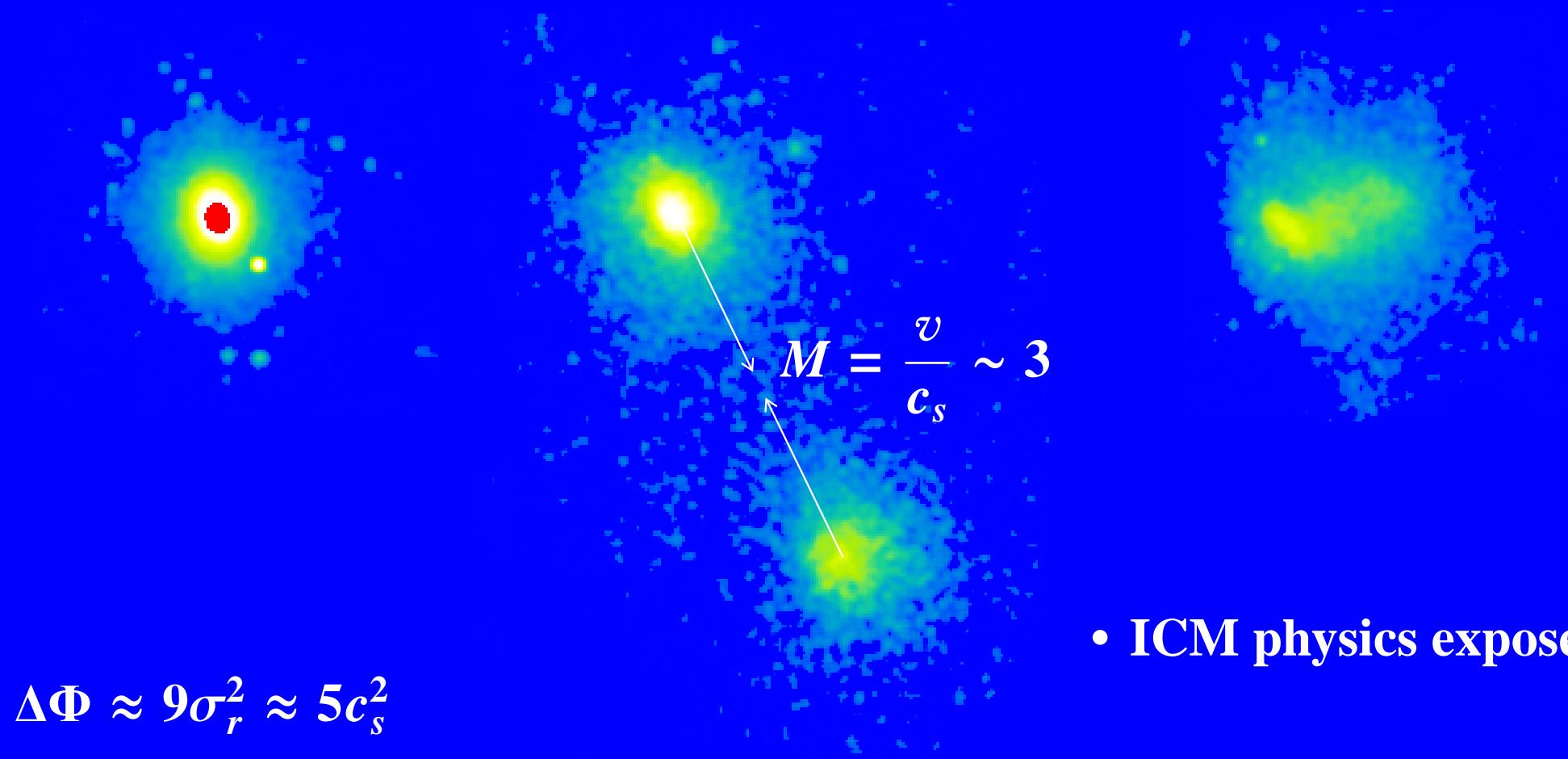


Cold Fronts and Shock Waves in Merging Clusters

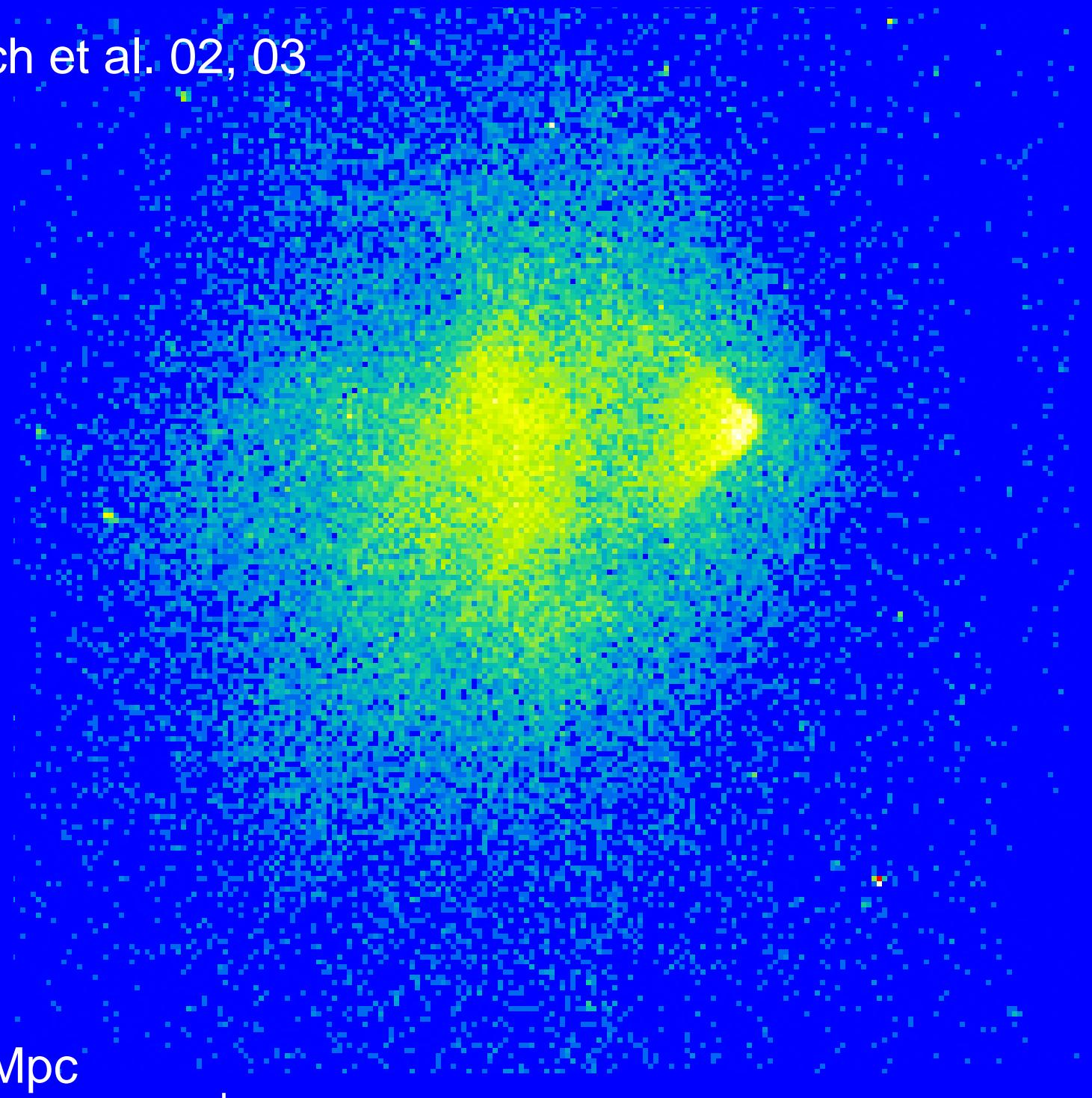
**A. Vikhlinin, M. Markevitch, P. Mazzotta,
W. Forman, C. Jones, S. Murray,
L. VanSpeybroeck, R. Kraft**

$$E_{\text{kin}} \sim 10^{63} \text{ erg} \gtrsim E_{\text{th}}$$



1E0657–56

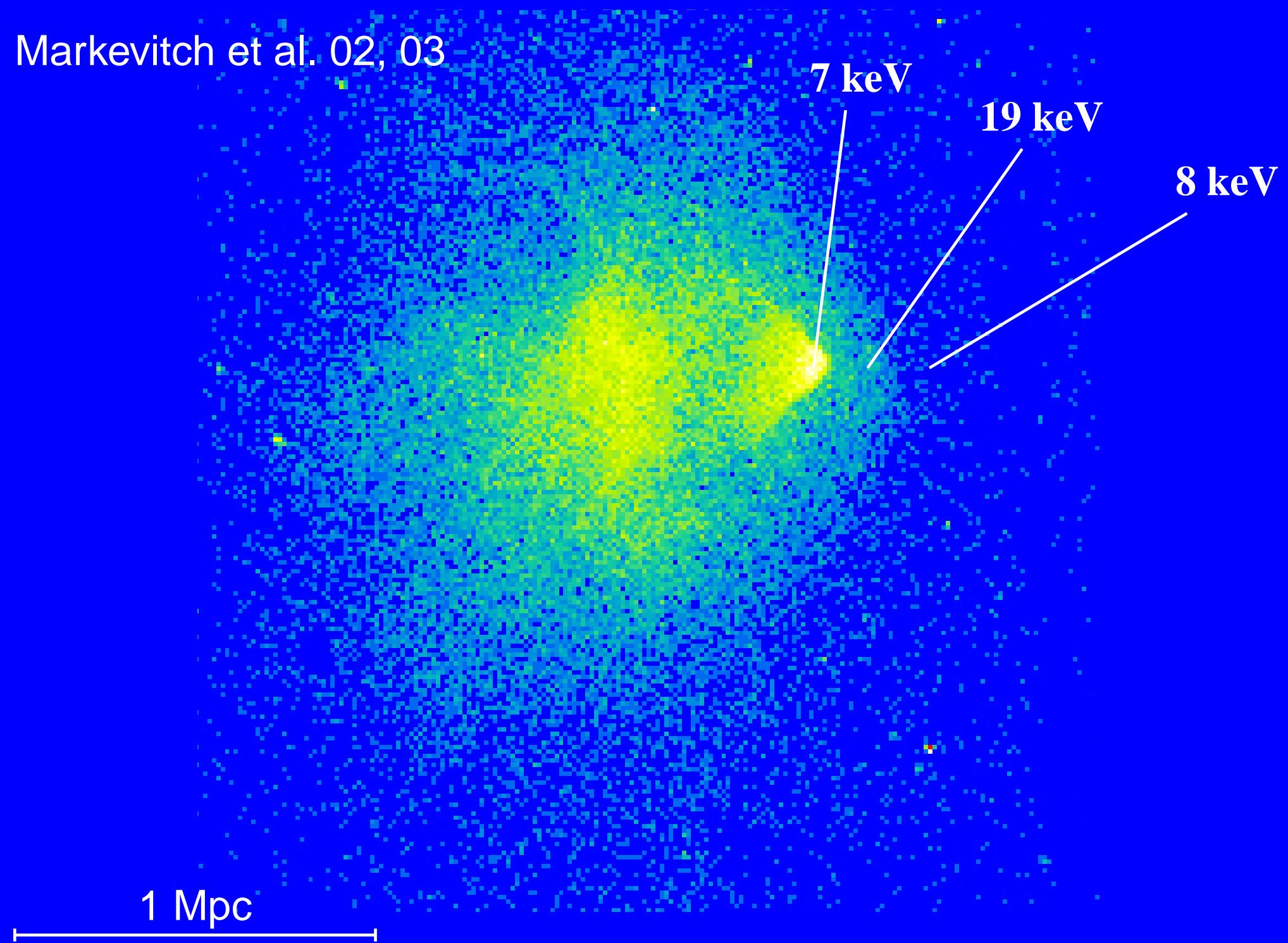
Markevitch et al. 02, 03



1 Mpc

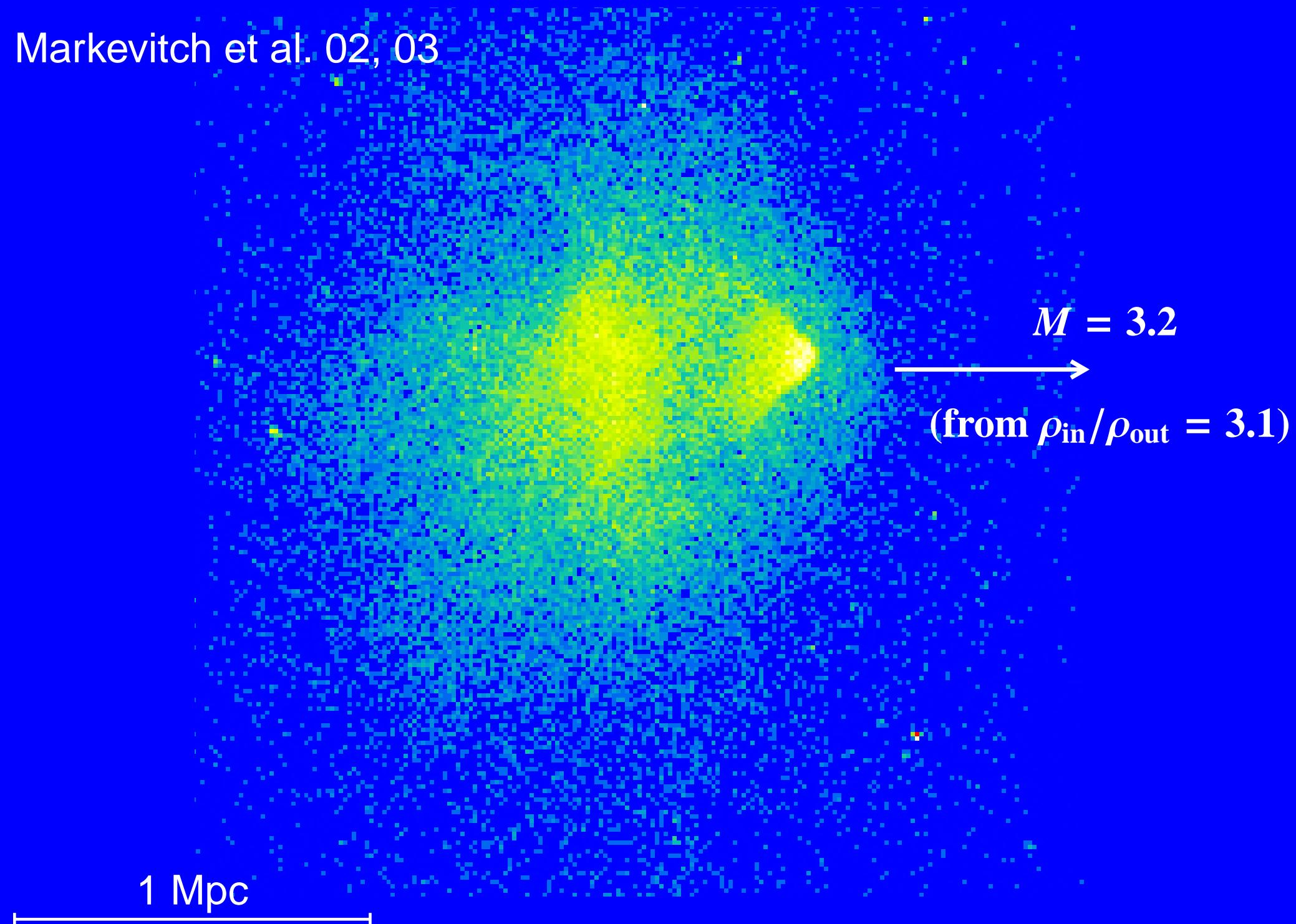
1E0657–56

Markevitch et al. 02, 03



1E0657–56

Markevitch et al. 02, 03



1E0657–56

Markevitch et al. 02, 03

1 Mpc

$$M = 3.2$$

(from $\rho_{\text{in}}/\rho_{\text{out}} = 3.1$)

$$\frac{T_{\text{in}}}{T_{\text{out}}} = 4.1 \text{ — expected}$$

$$\frac{T_{\text{in}}}{T_{\text{out}}} = 2.5 \pm 0.7 \text{ — observed}$$

1E0657–56

Markevitch et al. 02, 03

1 Mpc

$$M = 3.2$$

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$$\frac{T_{\text{in}}}{T_{\text{out}}} = 4.1 \text{ — expected}$$

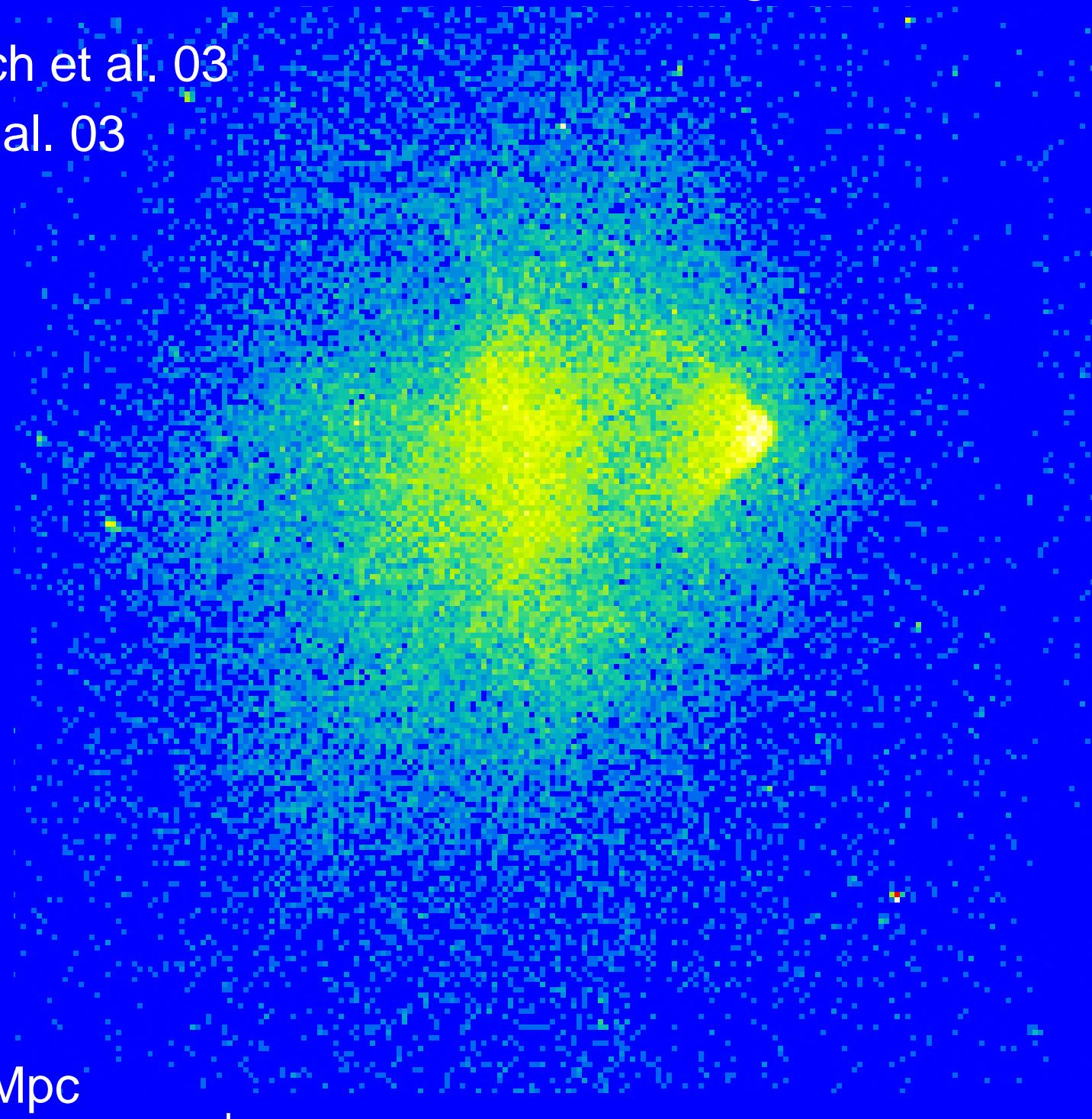
$$\frac{T_{\text{in}}}{T_{\text{out}}} = 2.5 \pm 0.7 \text{ — observed}$$

- electron-ion non-equilibrium?
- non-thermal processes?
- ...

1E0657–56: limits on self-interacting dark matter

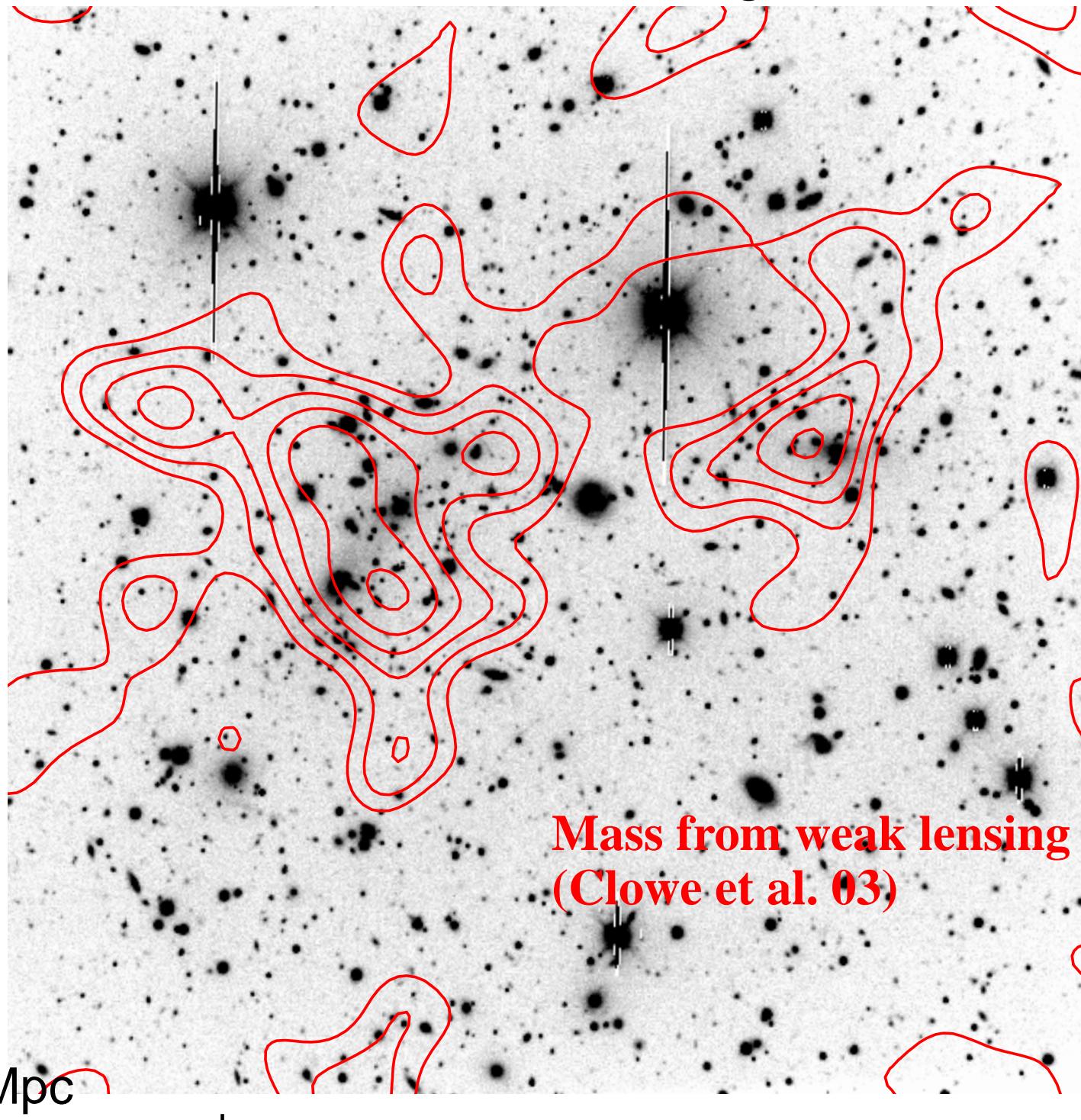
Markevitch et al. 03

Clowe et al. 03



1 Mpc

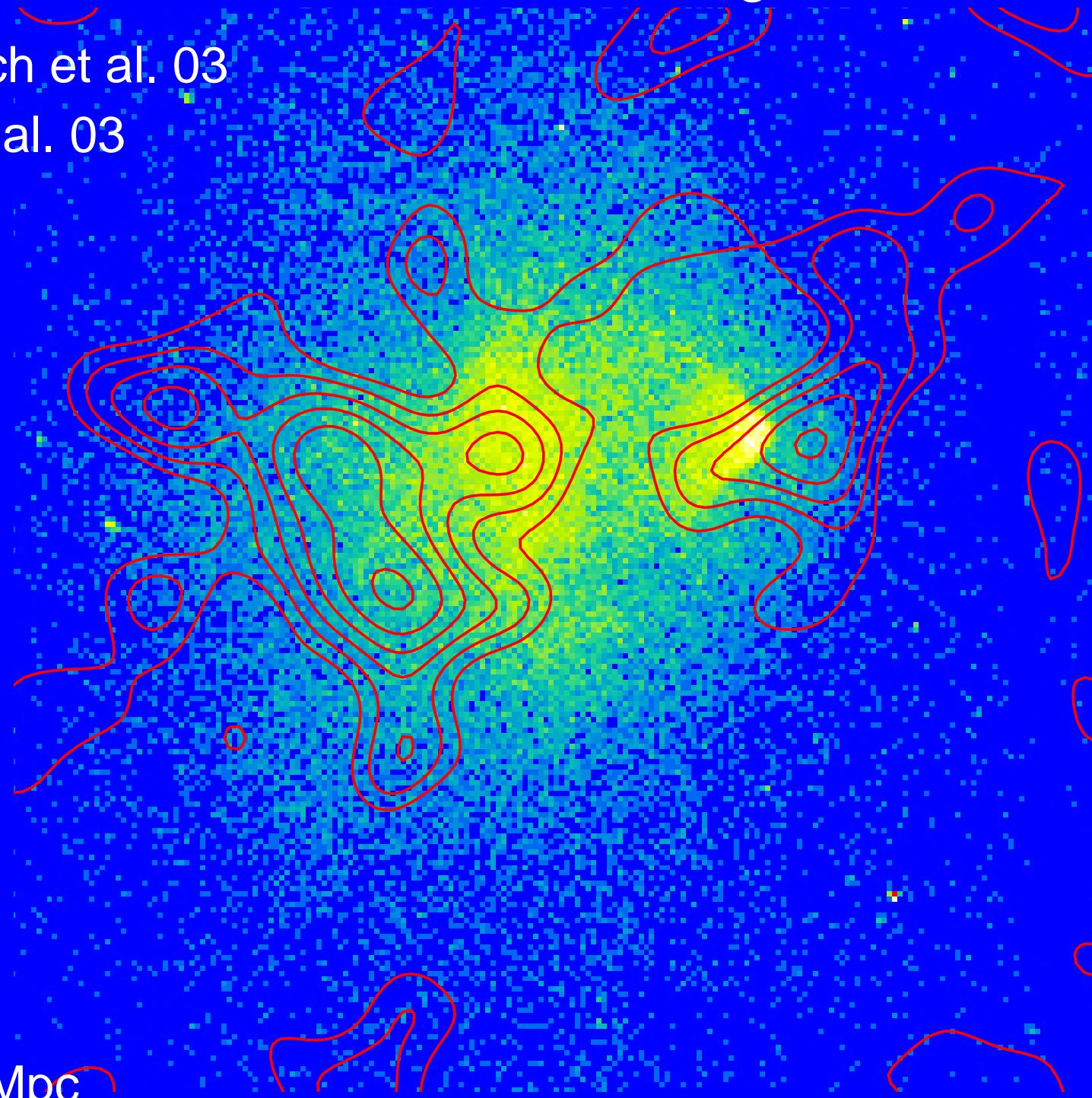
1E0657–56: limits on self-interacting dark matter



1E0657–56: limits on self-interacting dark matter

Markevitch et al. 03

Clowe et al. 03

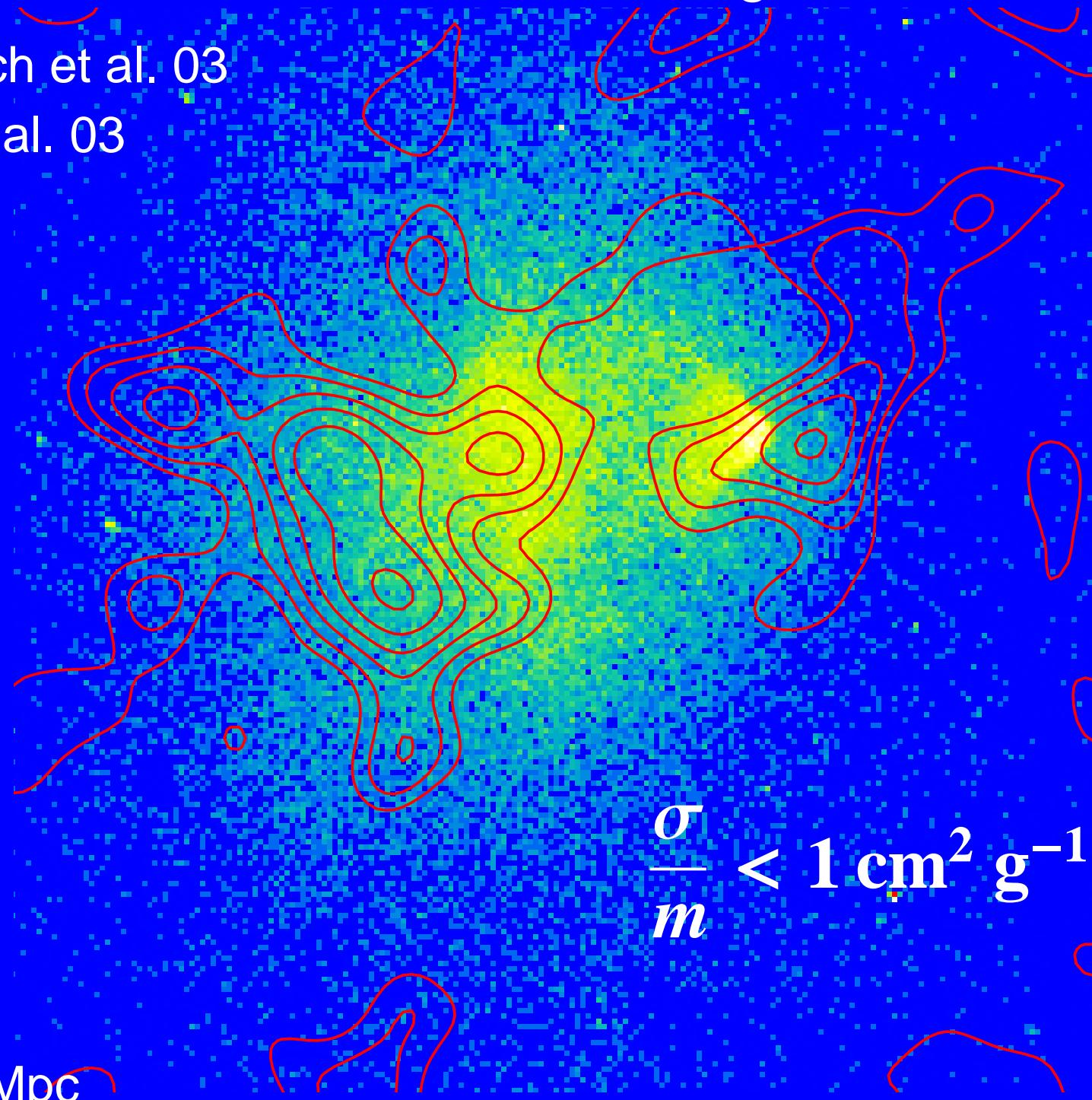


1 Mpc

1E0657–56: limits on self-interacting dark matter

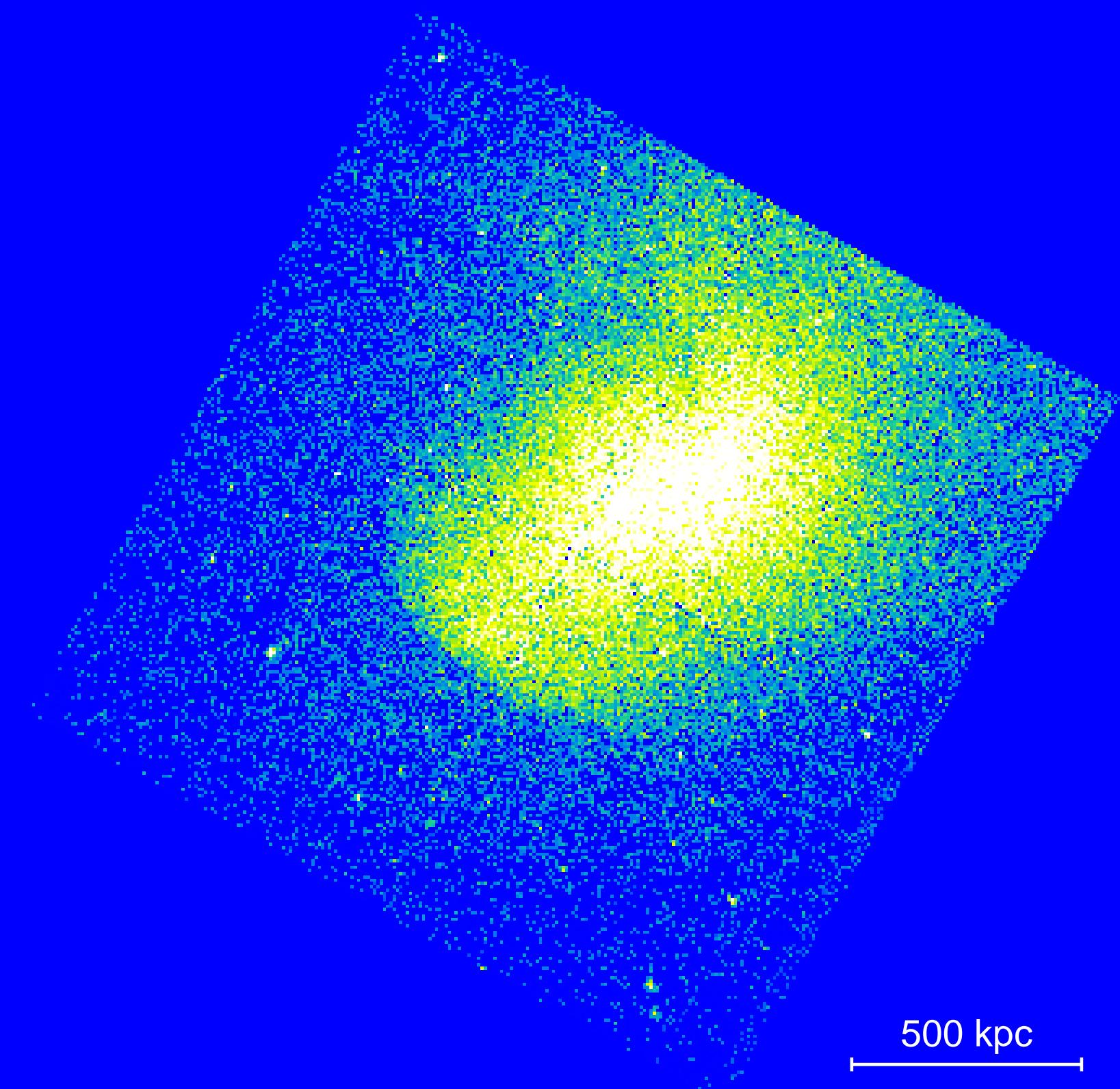
Markevitch et al. 03

Clowe et al. 03

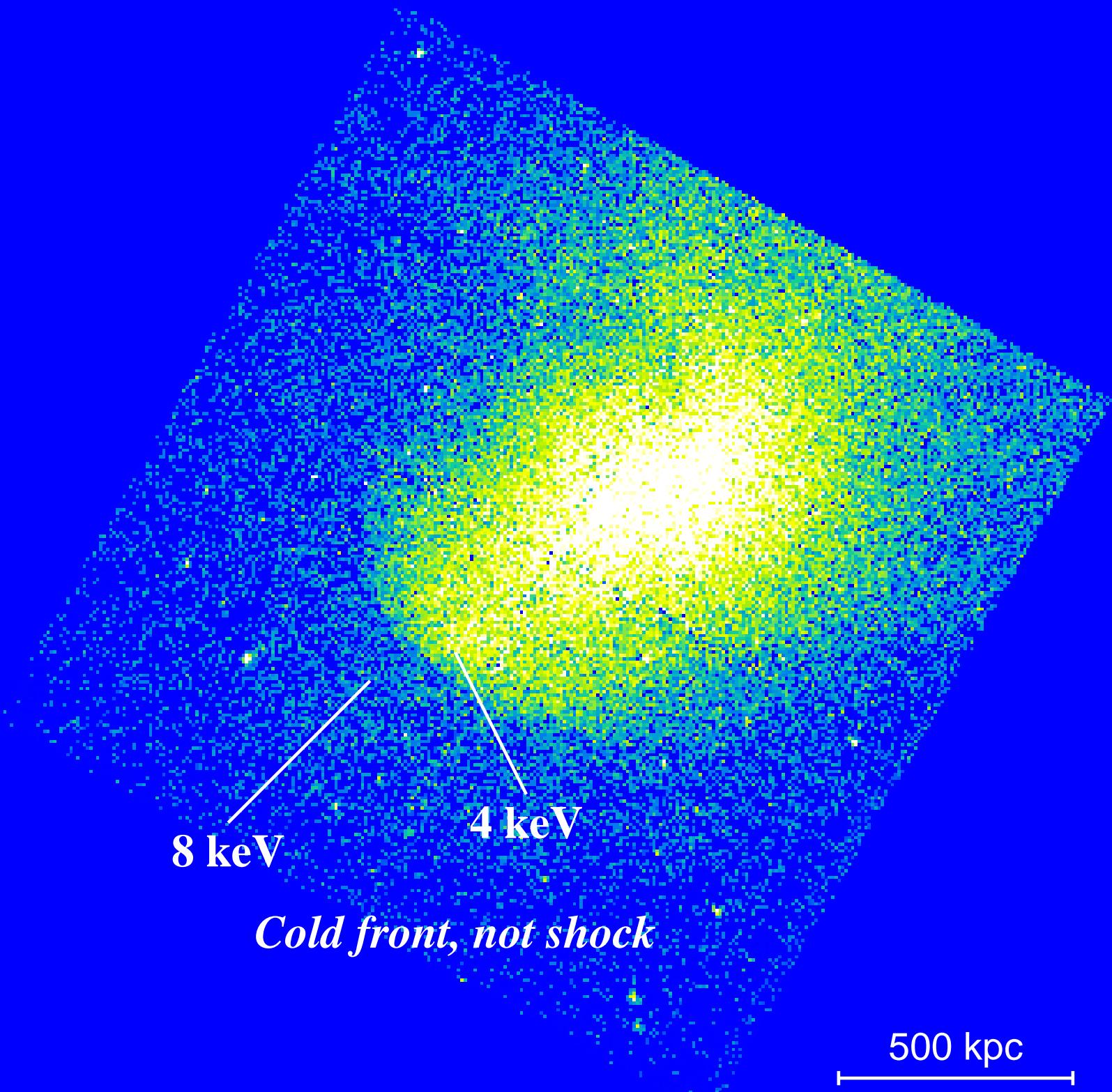


1 Mpc

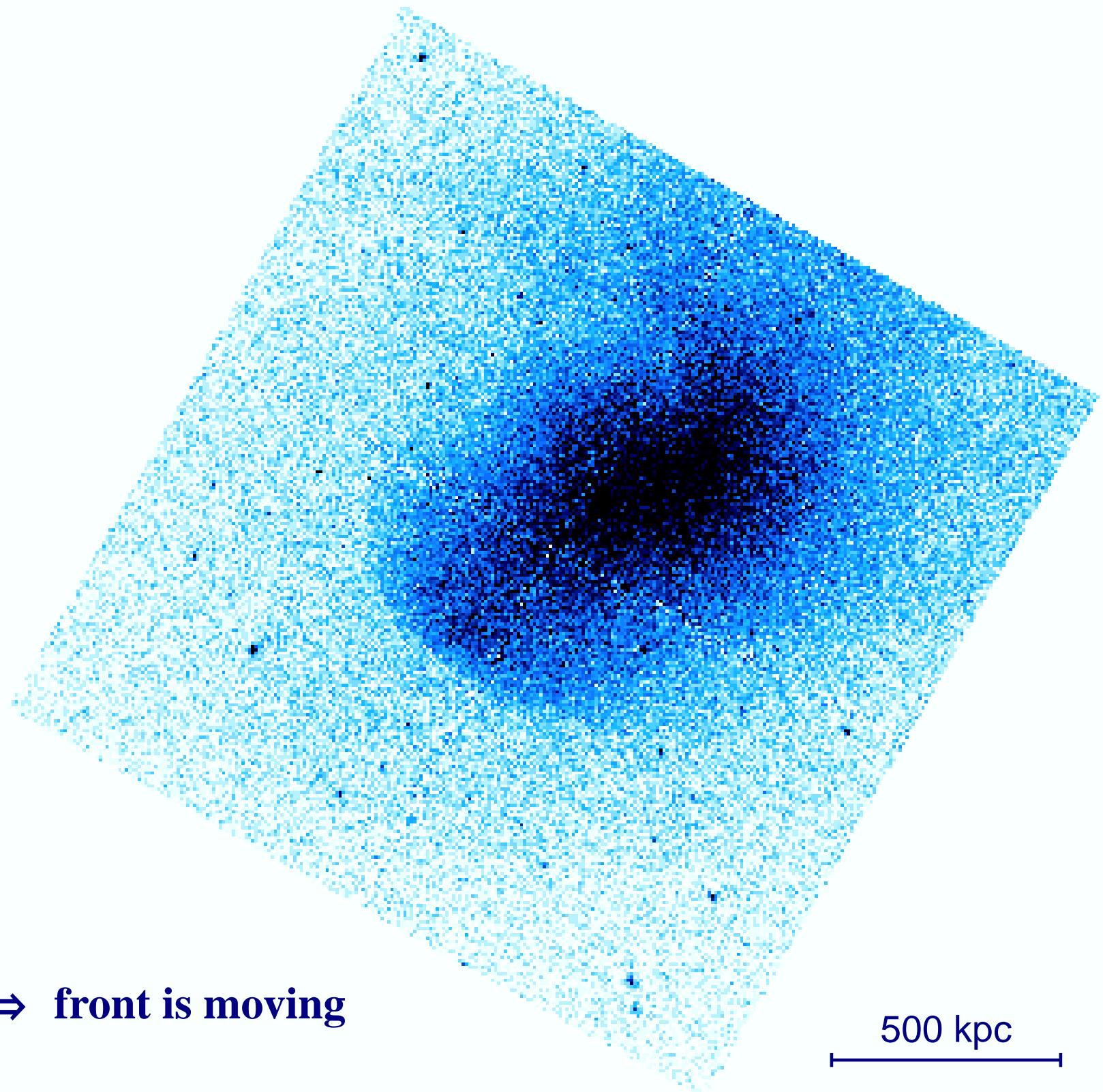
A3667



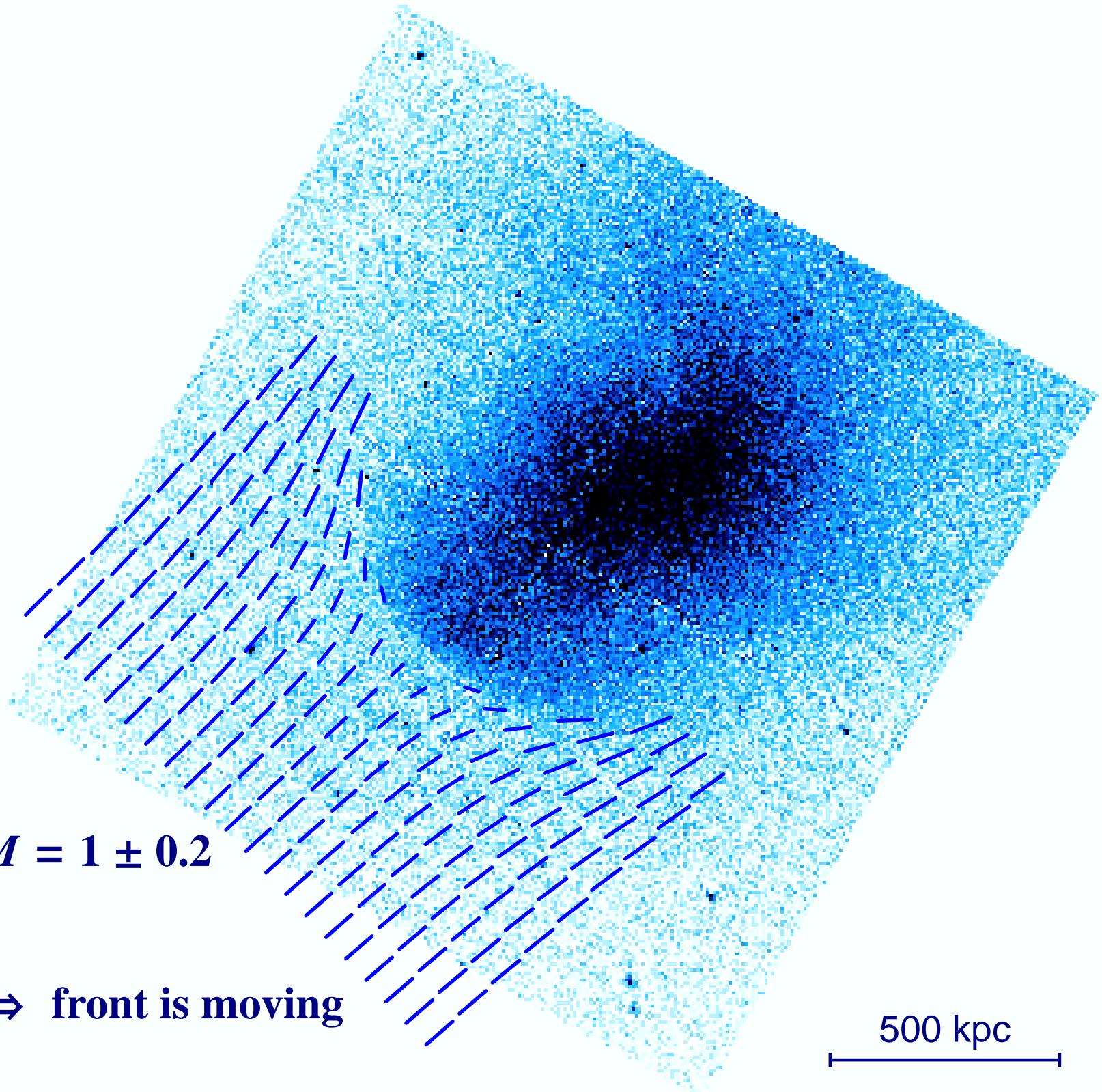
A3667



A3667

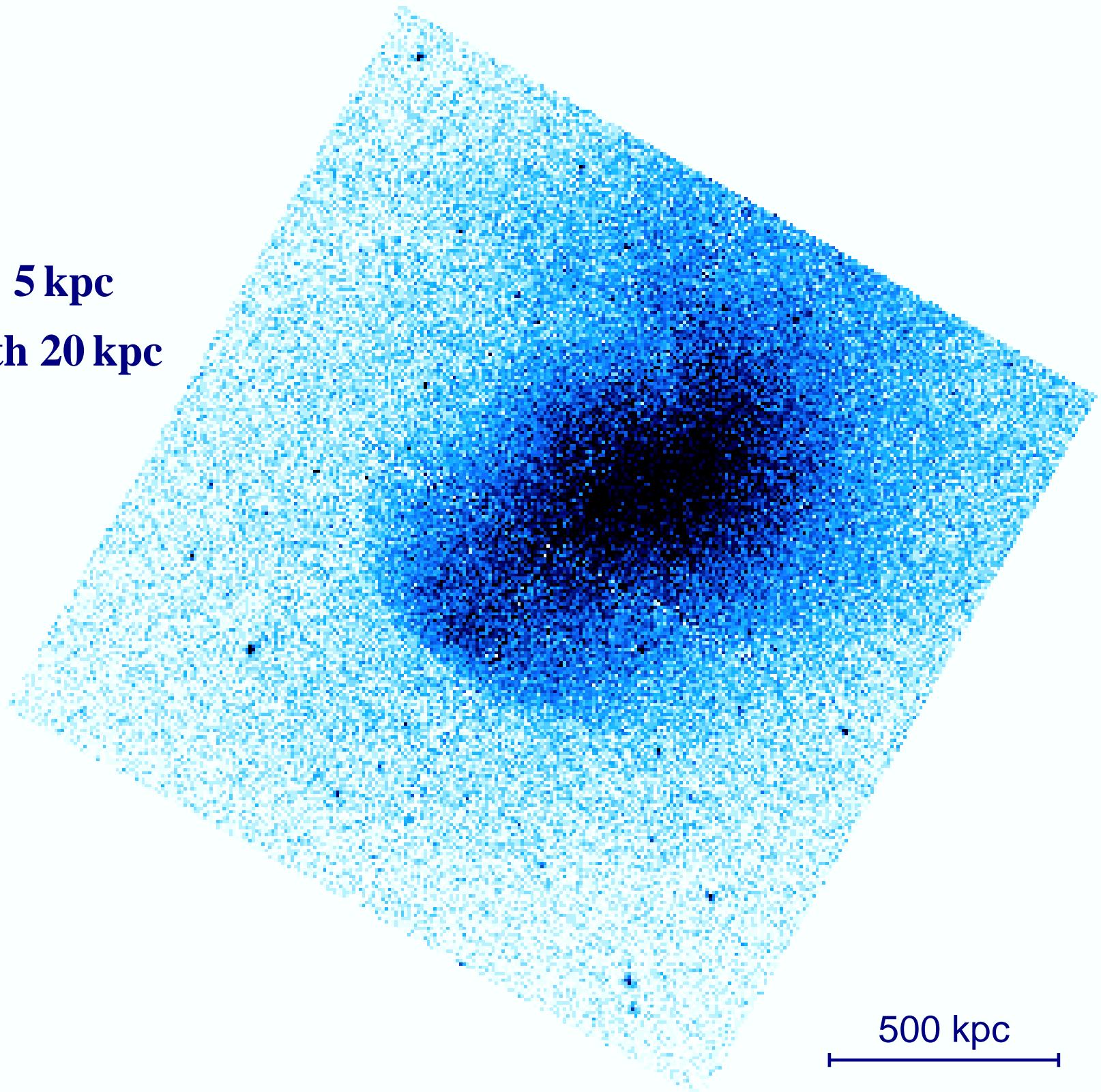


A3667



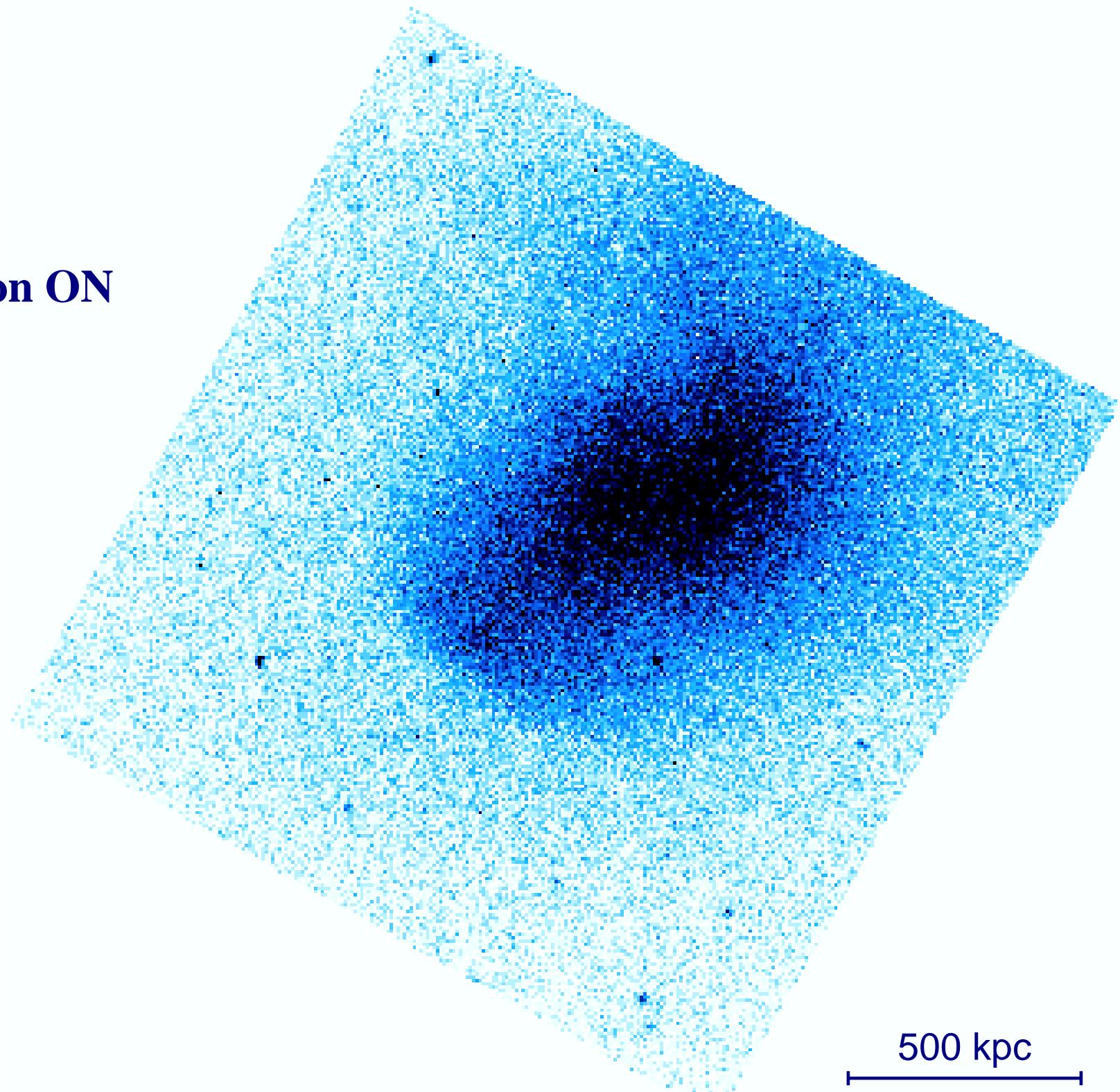
A3667

front width < 5 kpc
mean free path 20 kpc



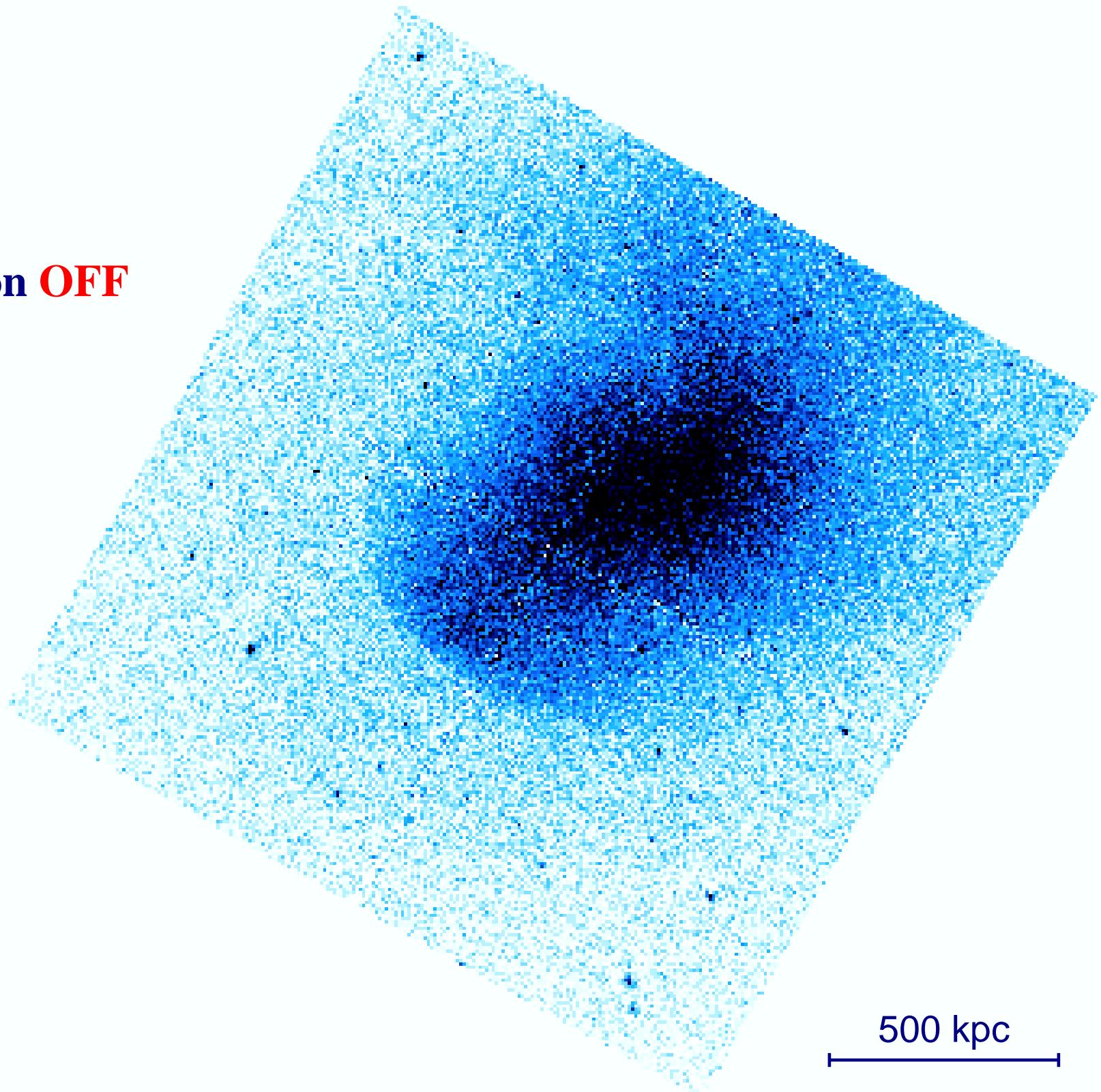
A3667

diffusion ON

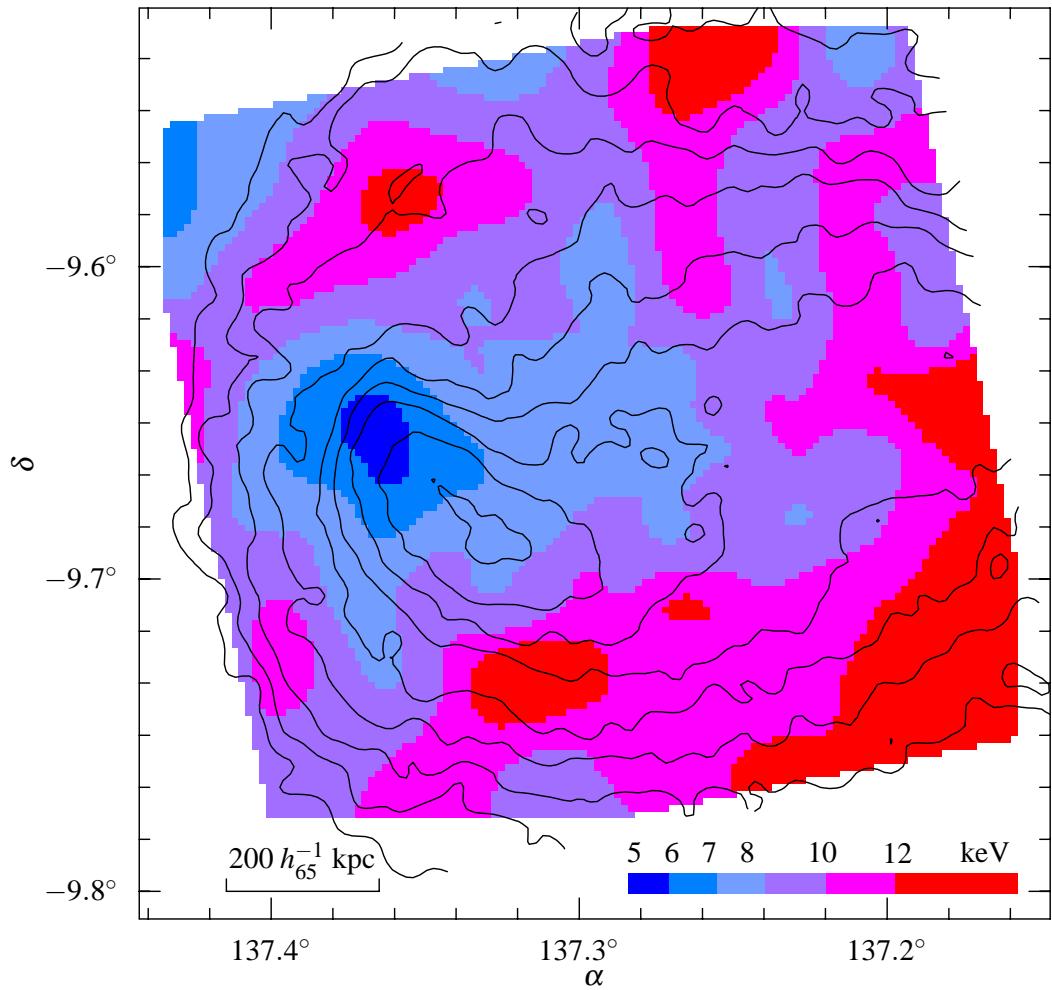


A3667

diffusion OFF



A754 — heat conduction in the bulk of the cluster gas



$$t_{\text{cond}} \sim \frac{k n_e l^2}{\kappa_{\text{sp}}} \simeq 1.2 \times 10^7 \text{ yr}$$

$$t_{\text{age}} \sim \frac{L}{c_s} \sim 5 \times 10^8 \text{ yr}$$



Conduction suppressed by factor

$$\frac{t_{\text{age}}}{t_{\text{cond}}} > 10 h_{65}^{1/2}$$

A3667

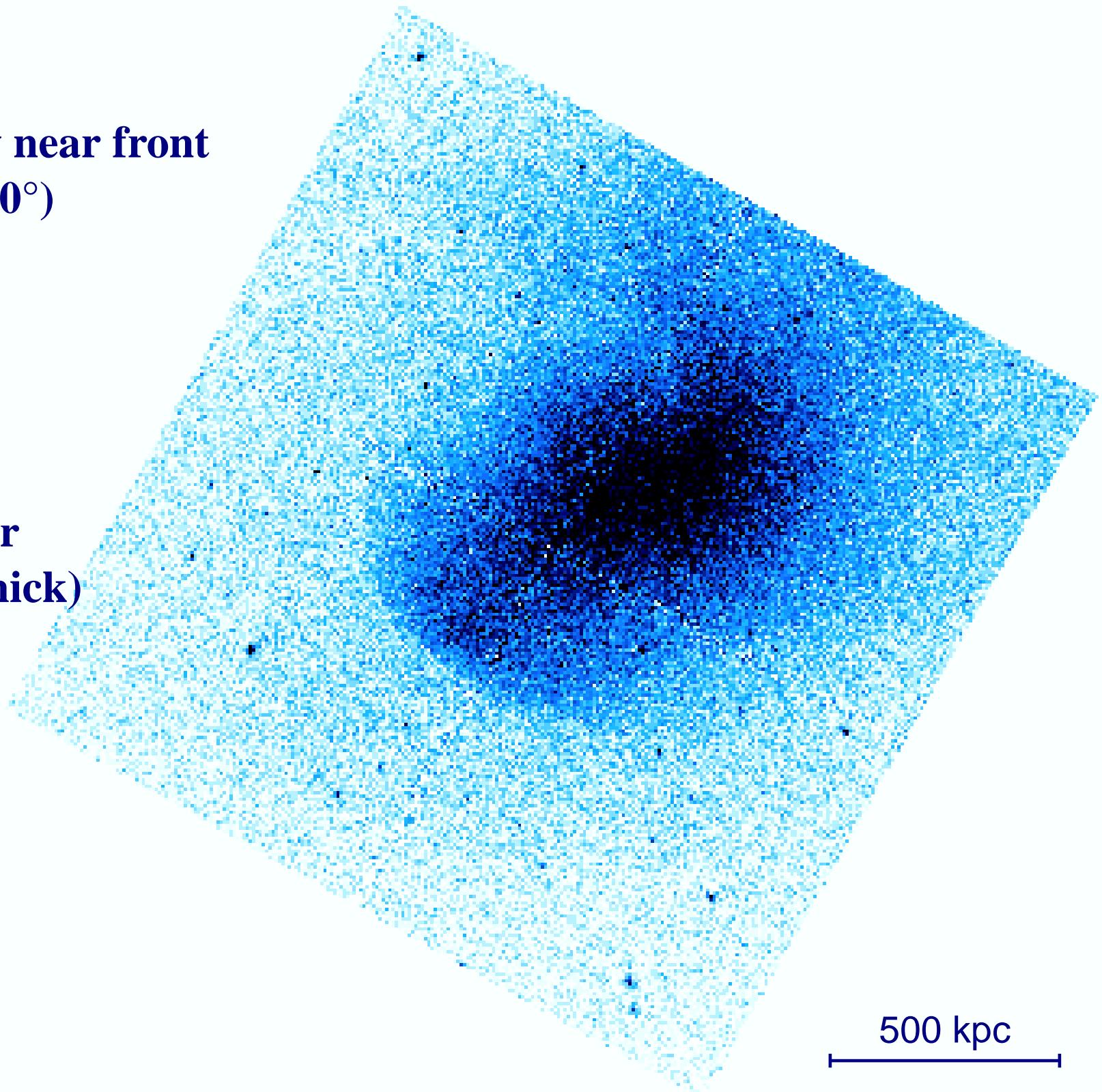
tangential flow near front
($M = 0.55$ at 30°)



KH-instability



Turbulent layer
(10 – 50 kpc thick)



500 kpc

A3667

tangential flow near front
($M = 0.55$ at 30°)



KH-instability

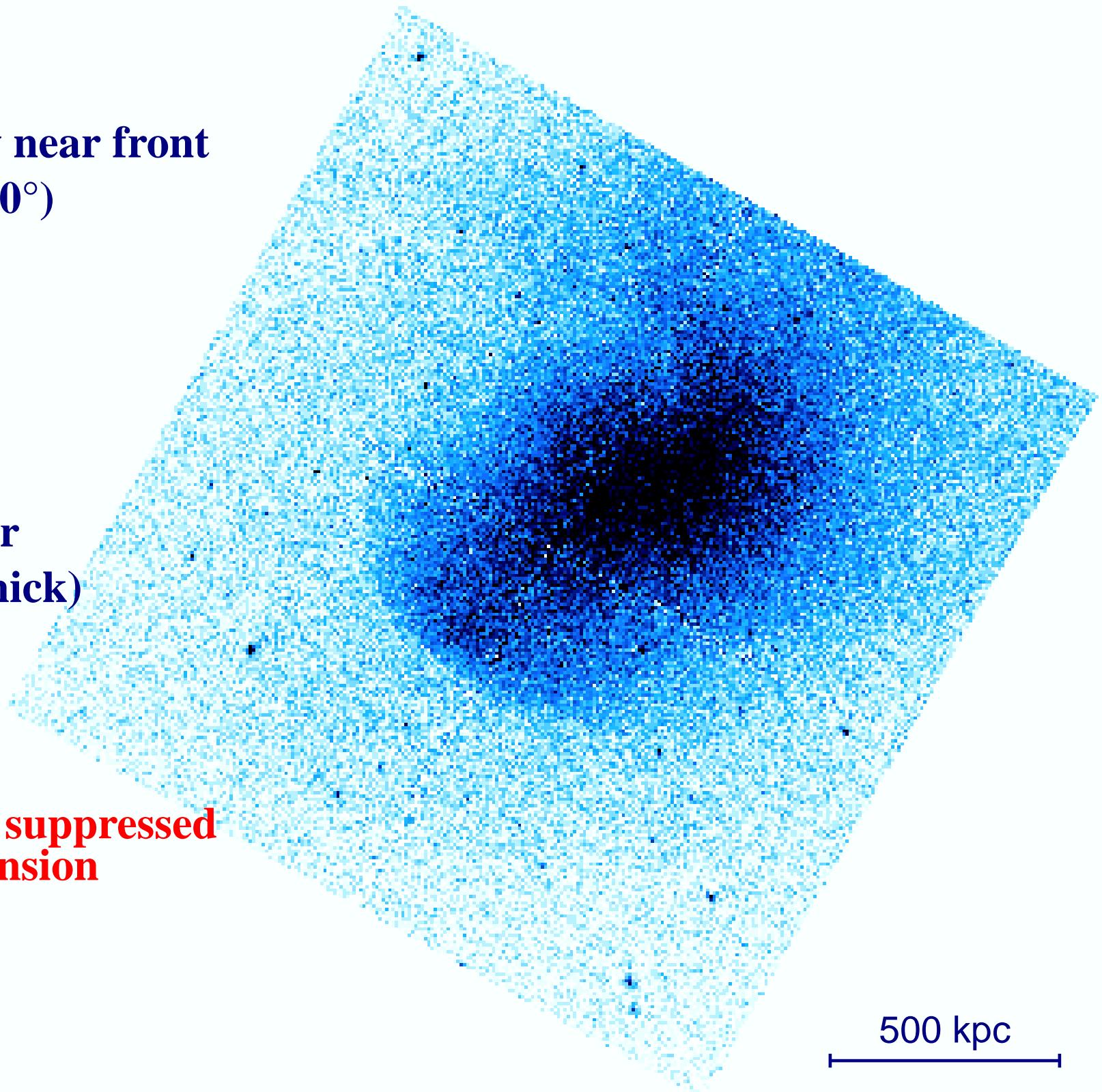


Turbulent layer
(10 – 50 kpc thick)

not observed



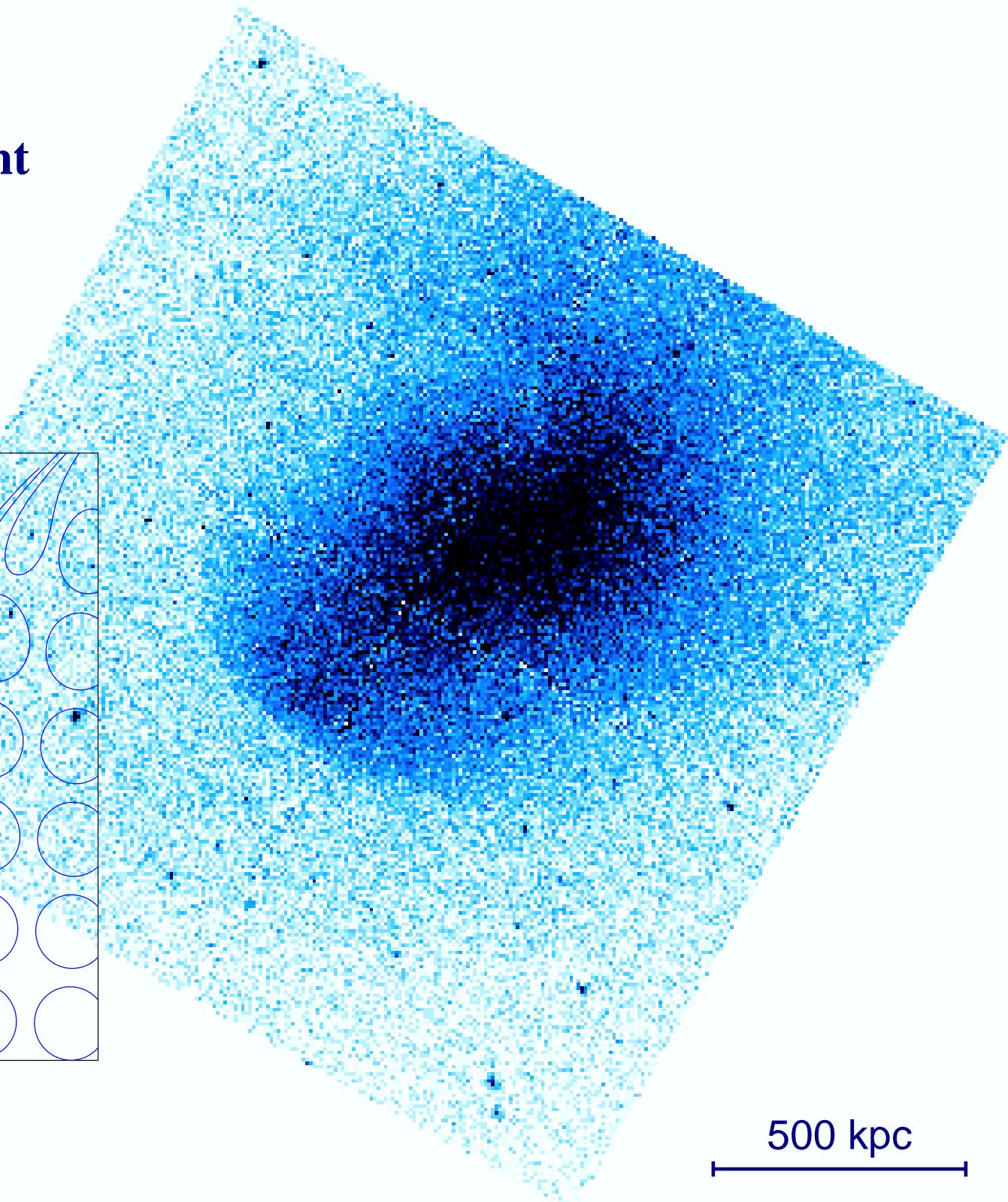
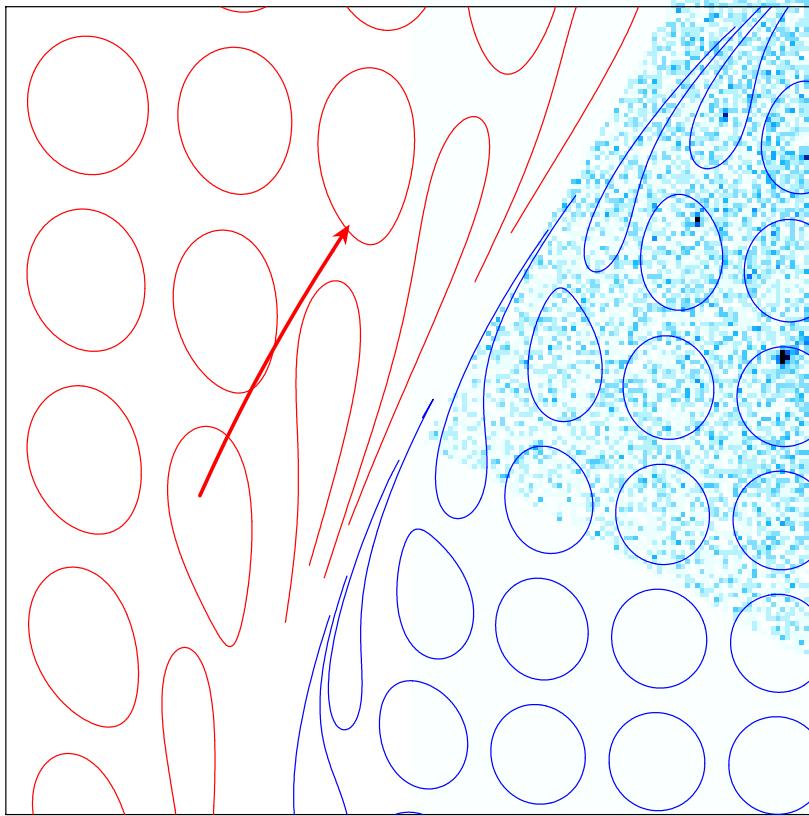
KH-instability suppressed
by magnetic tension



500 kpc

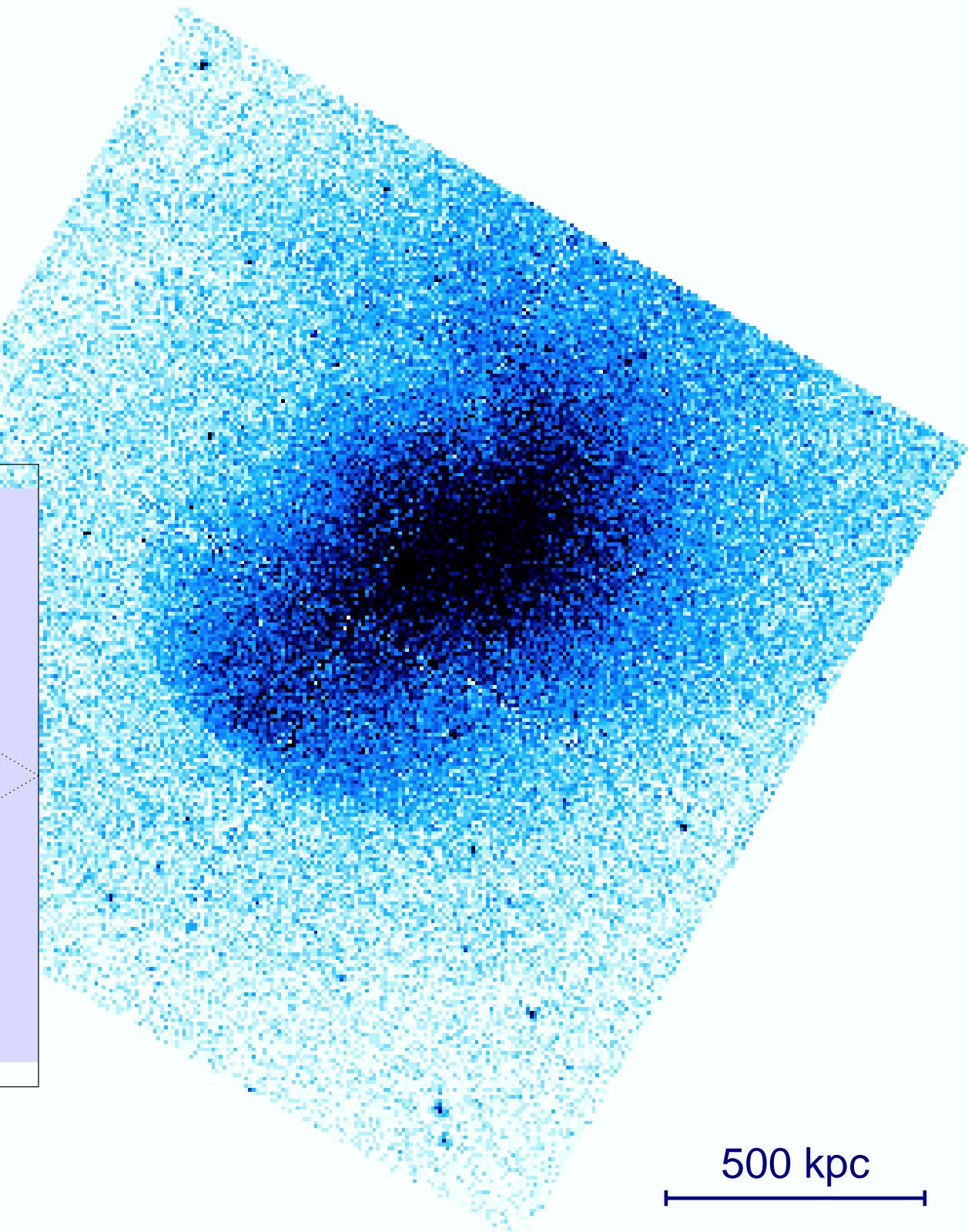
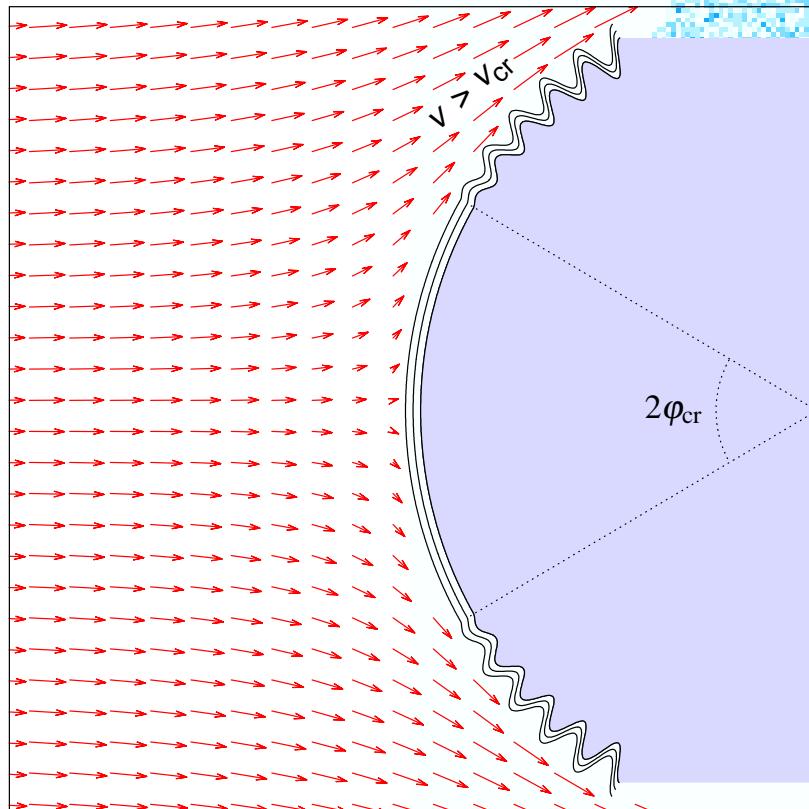
A3667

tangential flow near front
($M = 0.55$ at 30°)



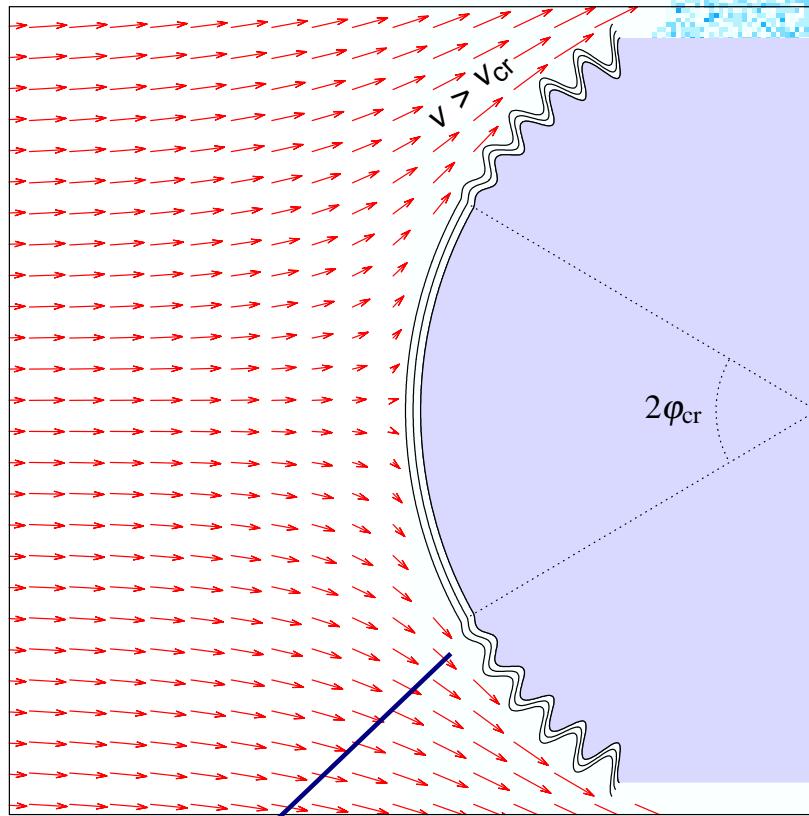
A3667

tangential flow near front
($M = 0.55$ at 30°)

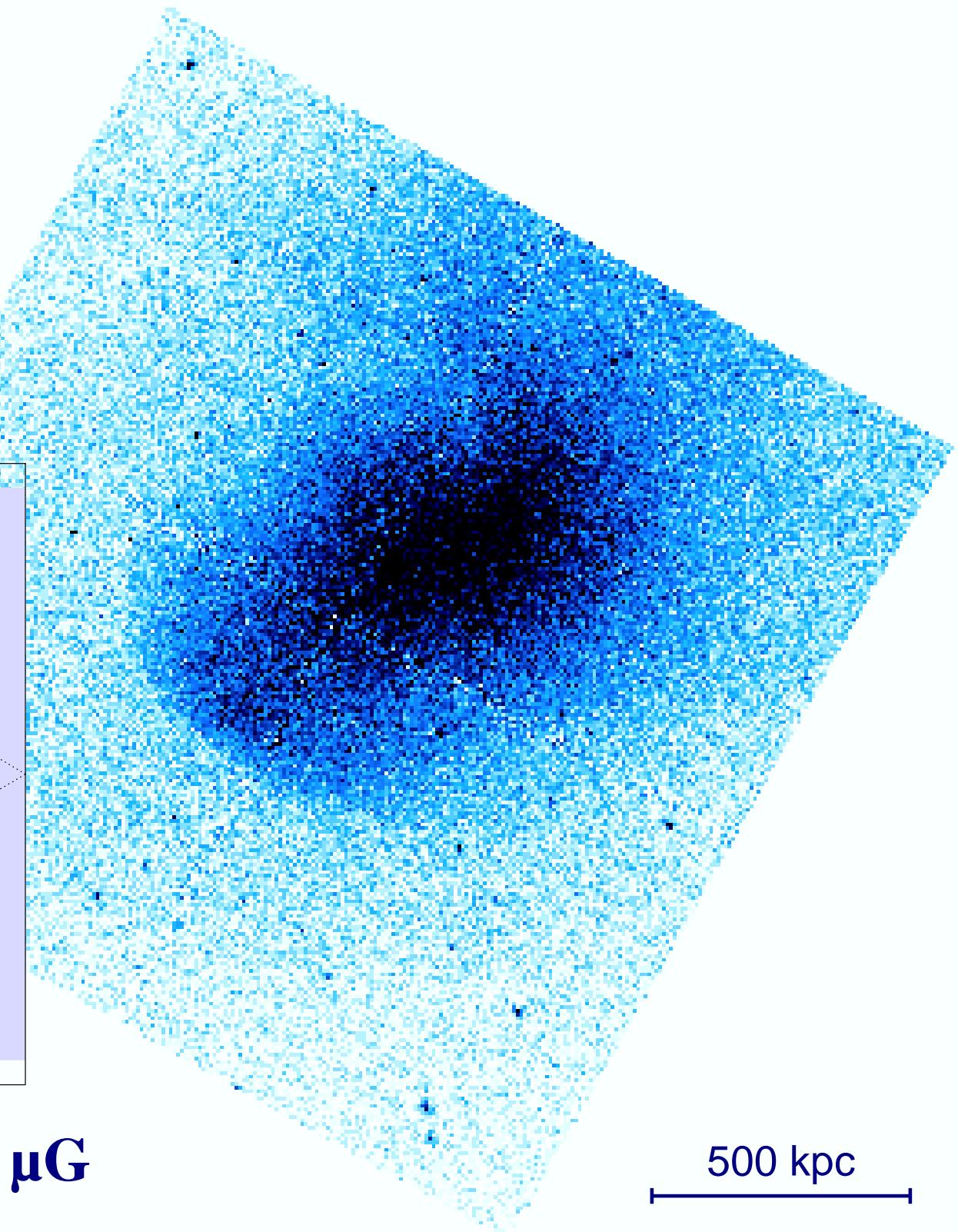


A3667

tangential flow near front
($M = 0.55$ at 30°)

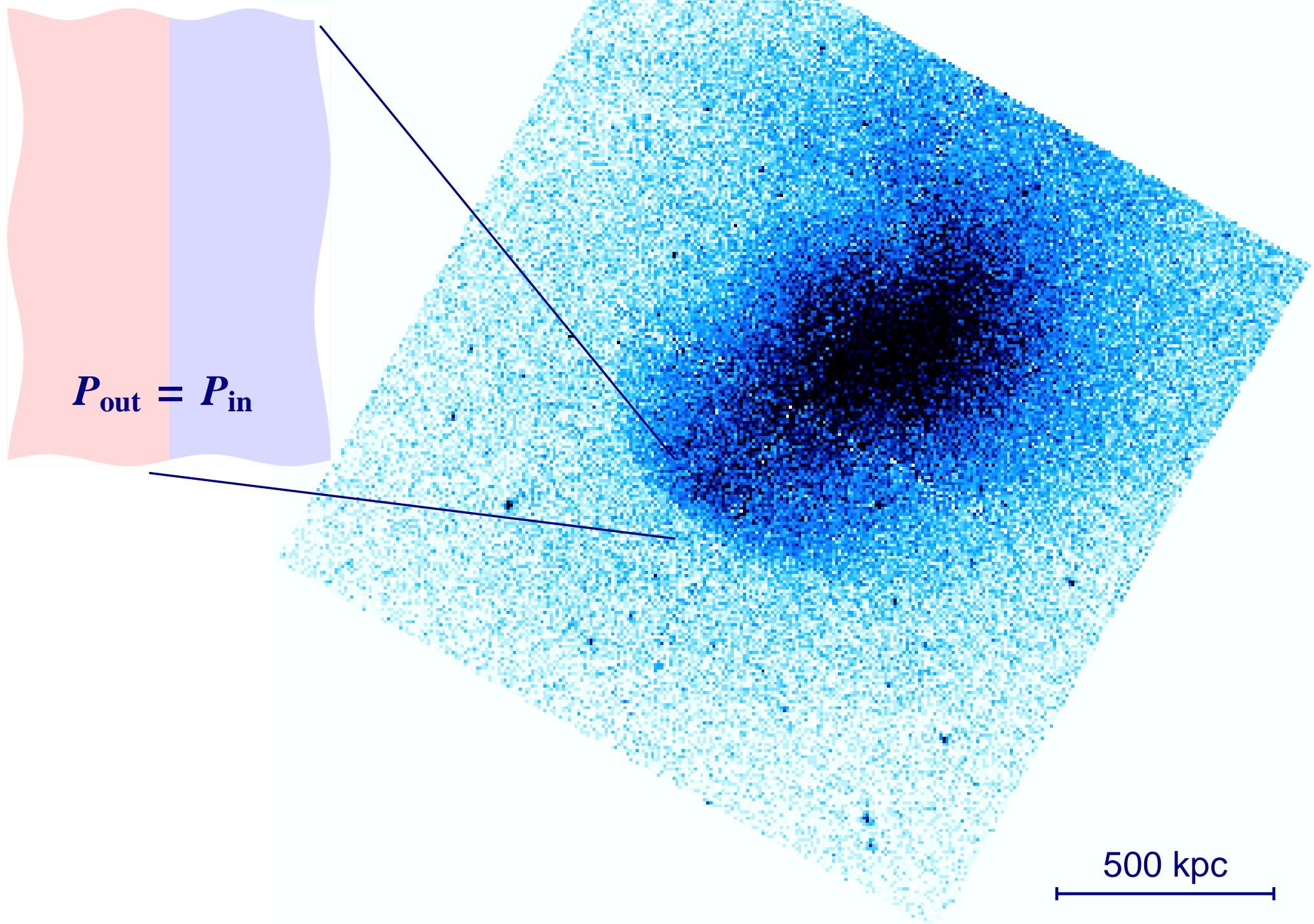


$P_{\text{mag}} \approx 0.1 P_{\text{th}}, B \approx 10 \mu\text{G}$



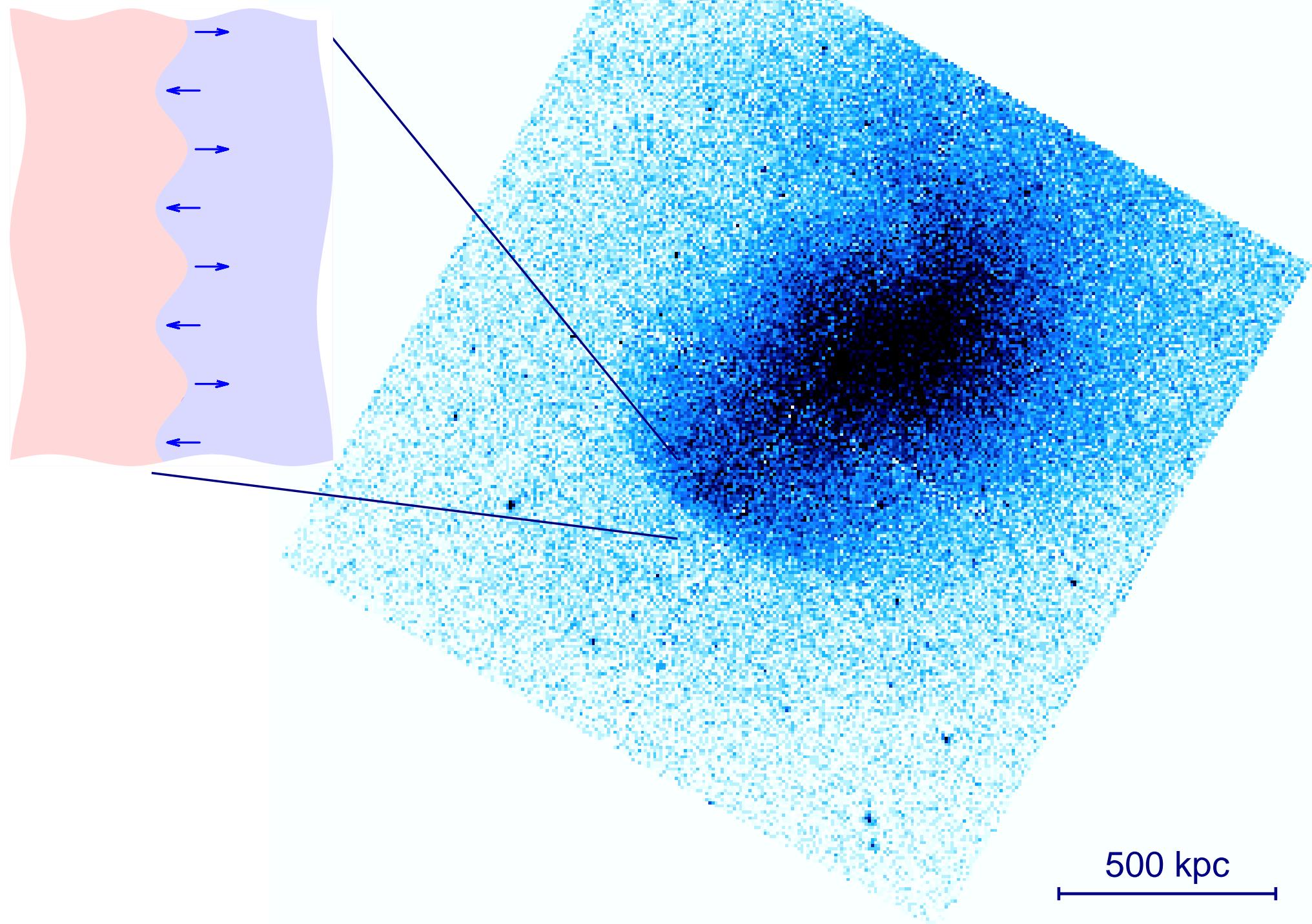
A3667

limits on turbulence



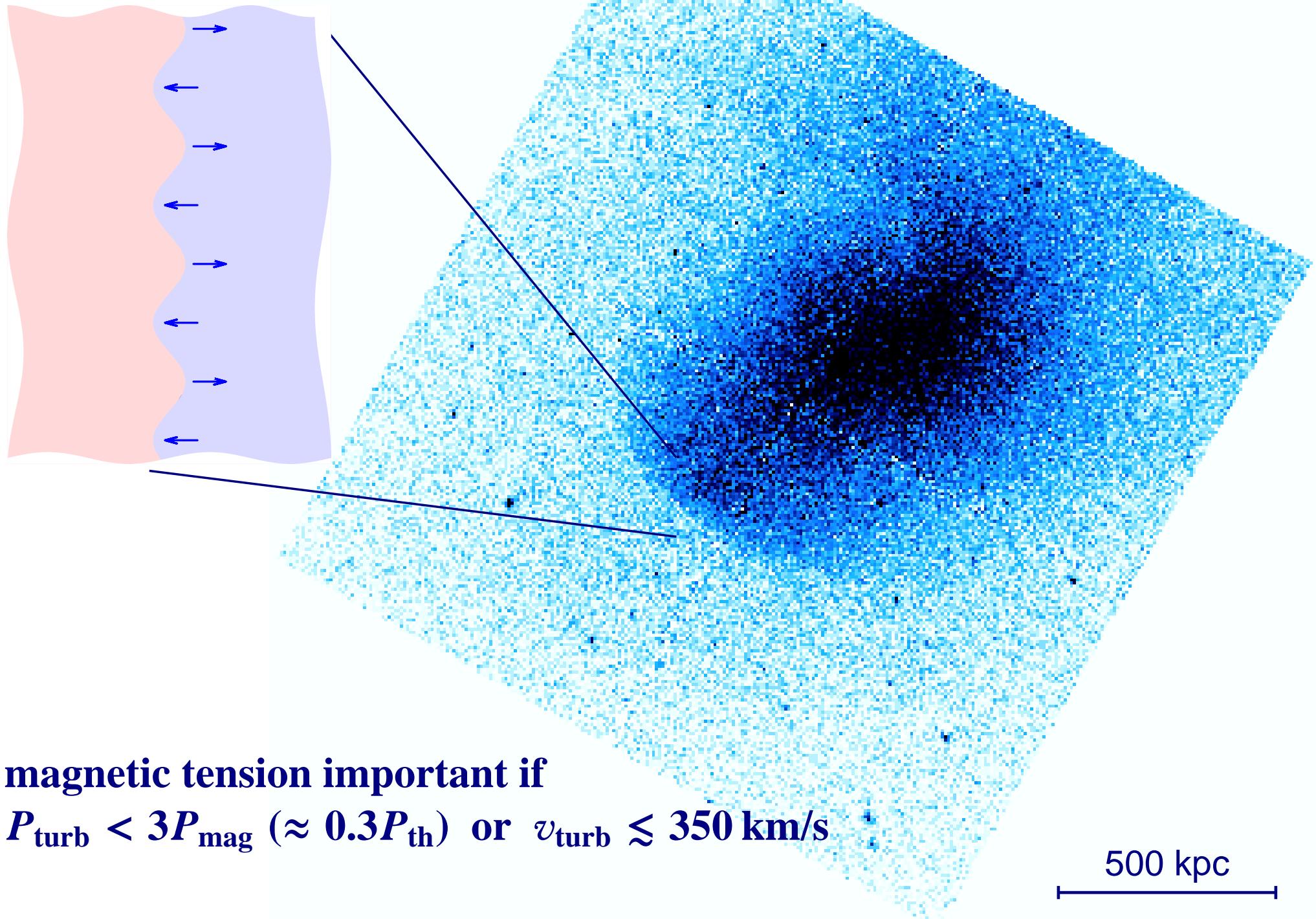
A3667

limits on turbulence



A3667

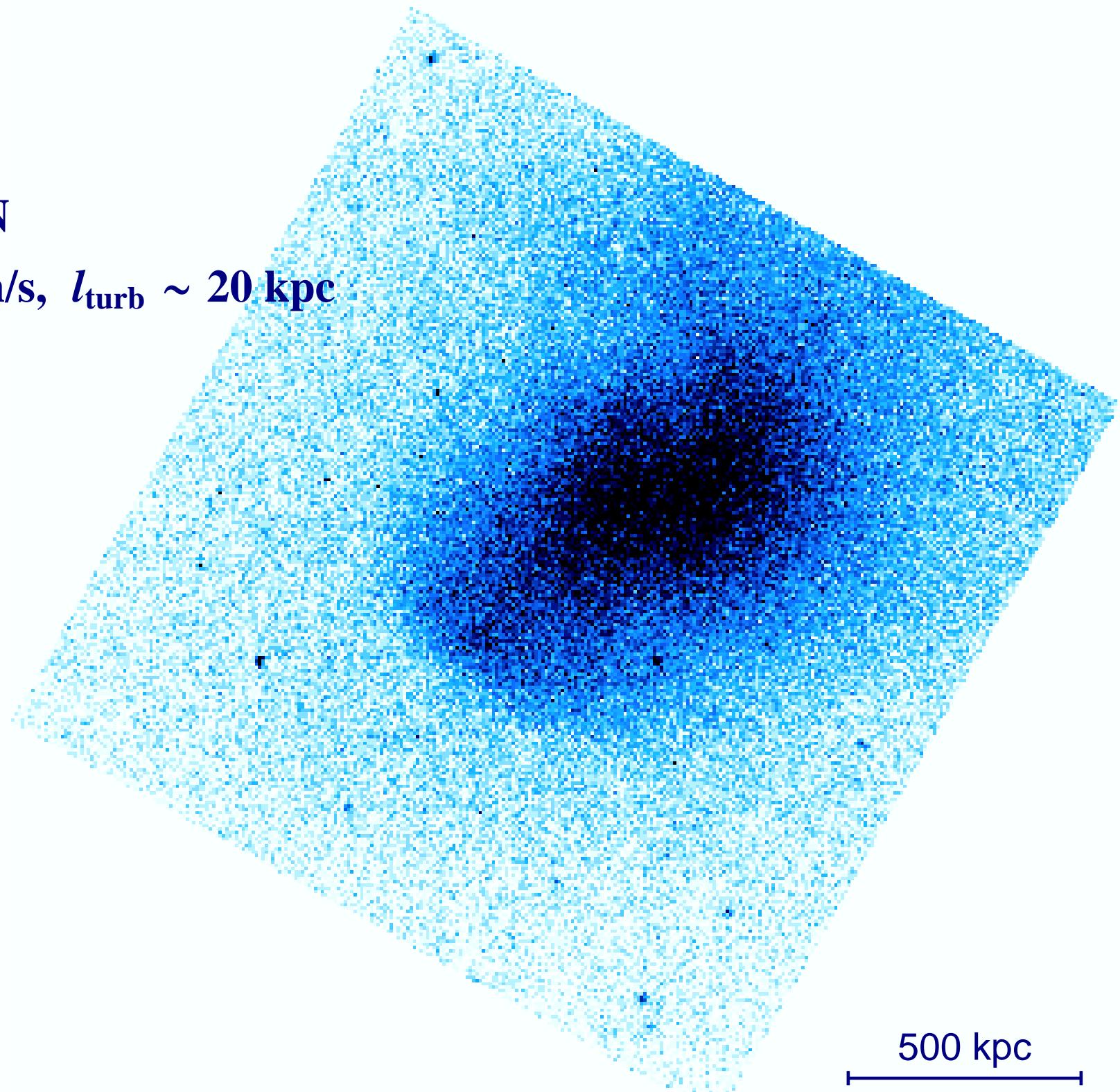
limits on turbulence



A3667

turbulence ON

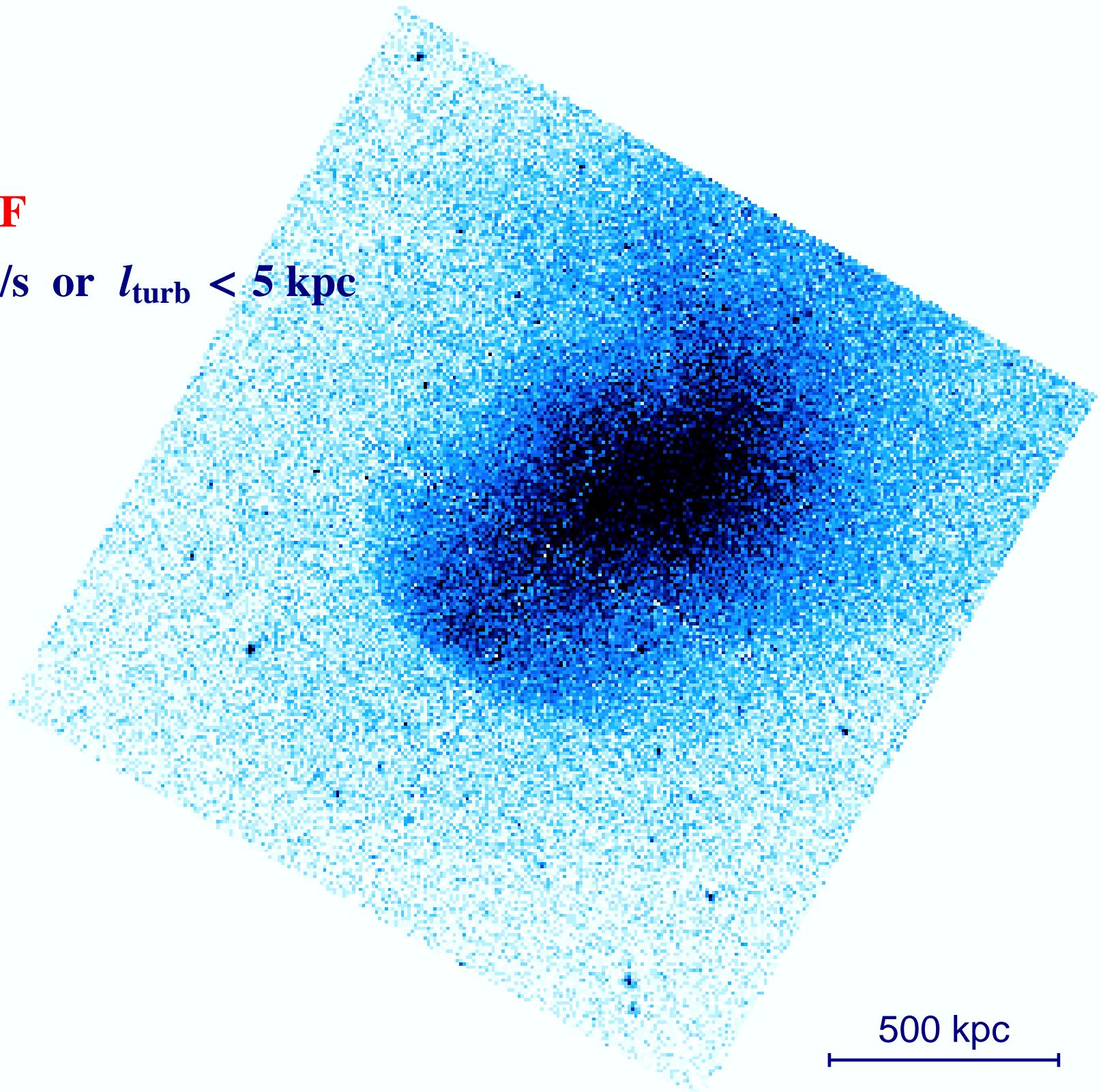
$v_{\text{turb}} > 350 \text{ km/s}$, $l_{\text{turb}} \sim 20 \text{ kpc}$



A3667

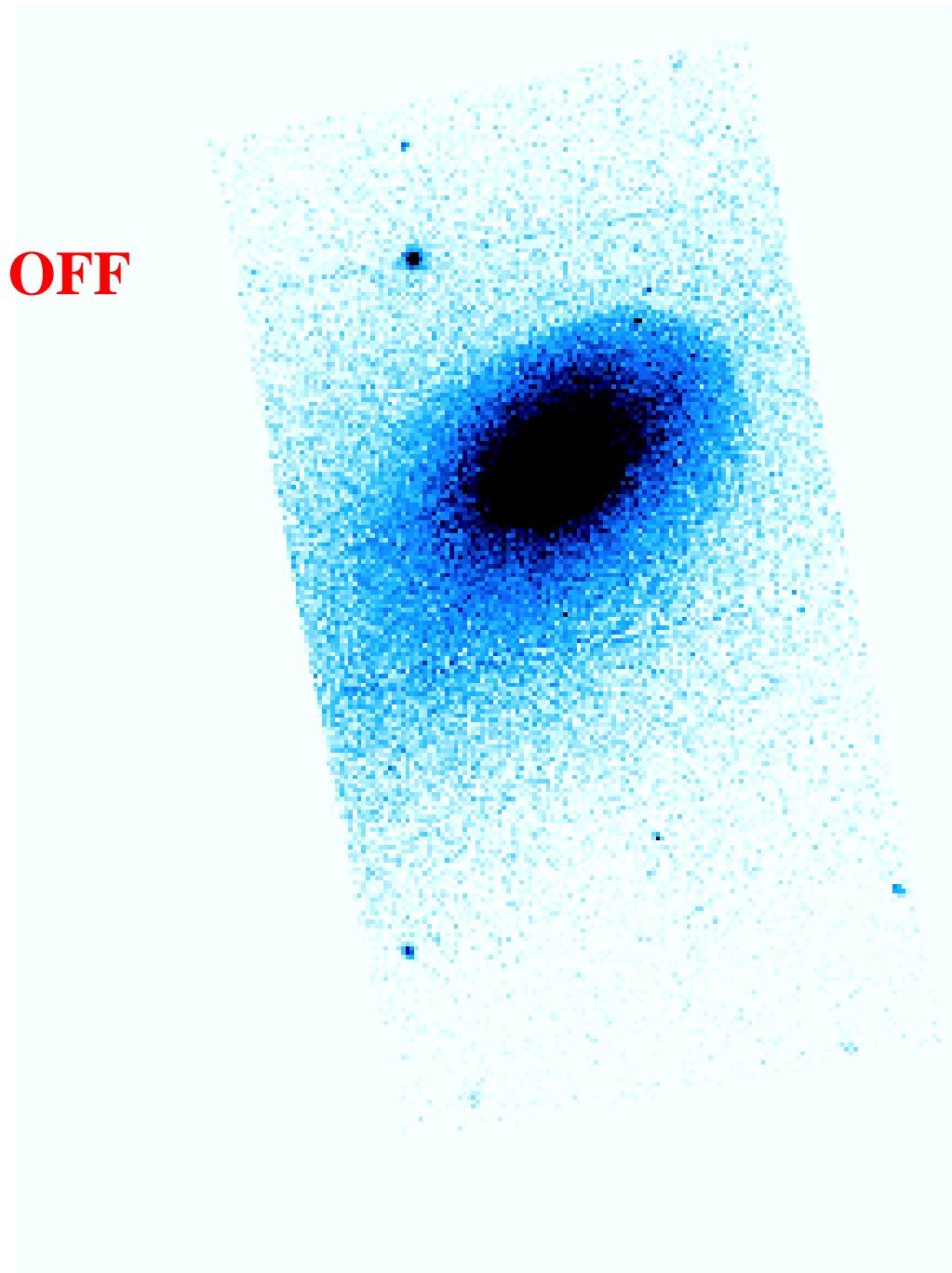
turbulence **OFF**

$v_{\text{turb}} < 350 \text{ km/s}$ or $l_{\text{turb}} < 5 \text{ kpc}$



A2142

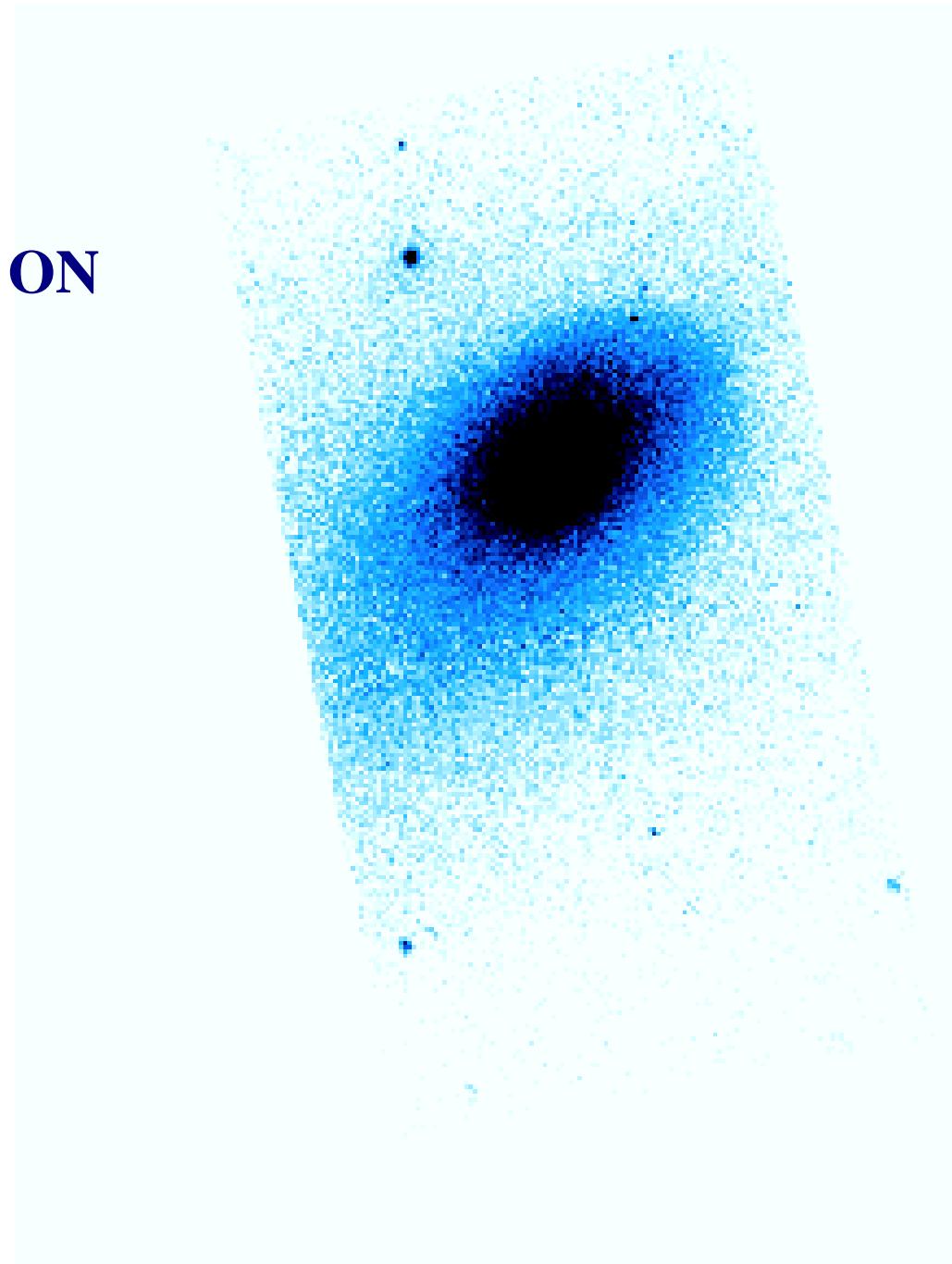
diffusion, turbulence OFF



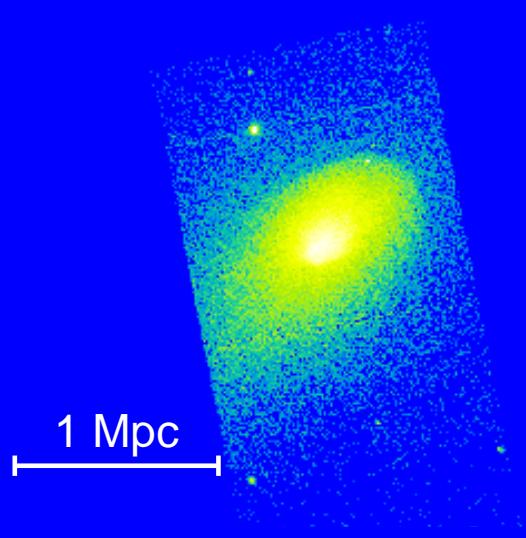
A2142

diffusion, turbulence ON

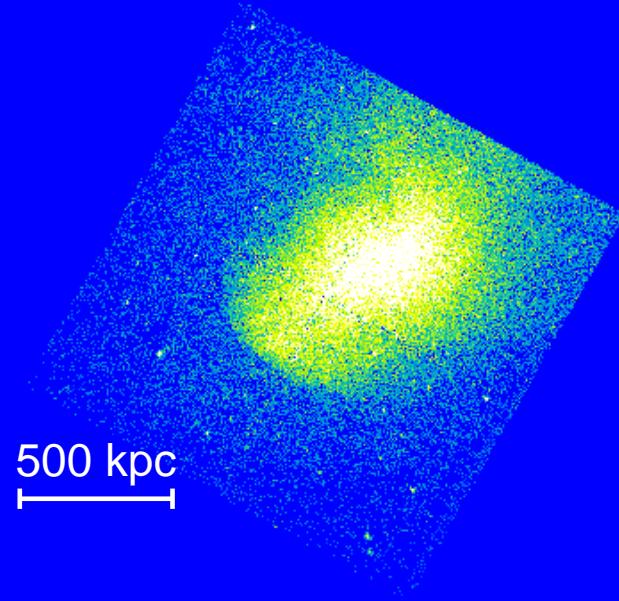
$\lambda = 25 \text{ kpc}$



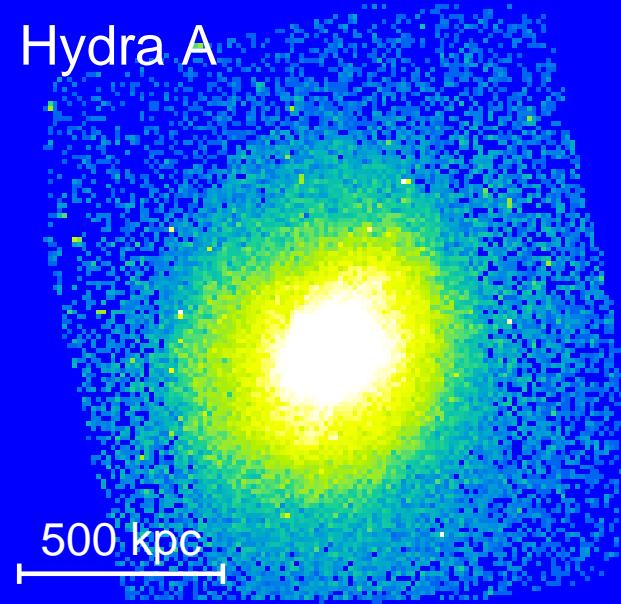
A2142



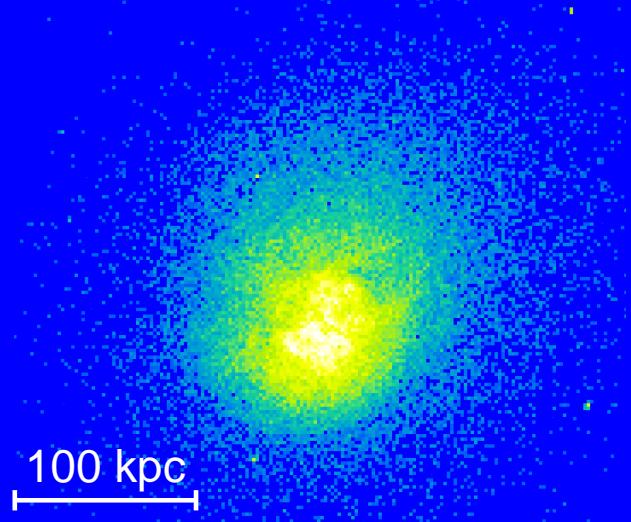
A3667



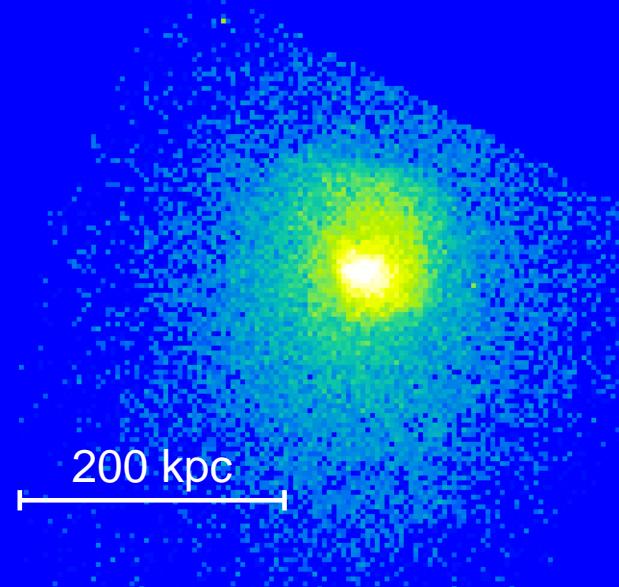
Hydra A



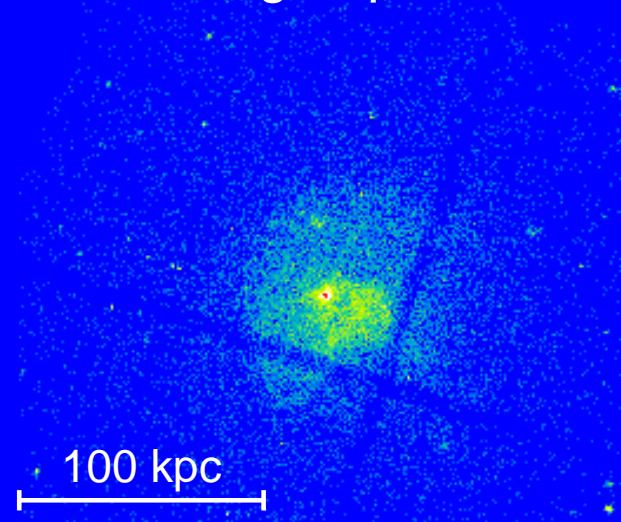
2A 0335+096



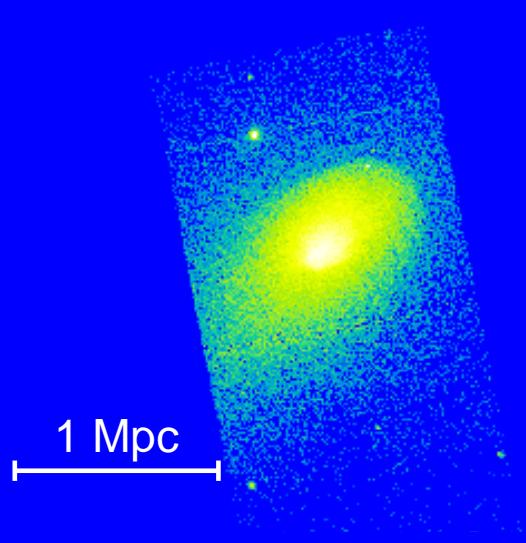
A496



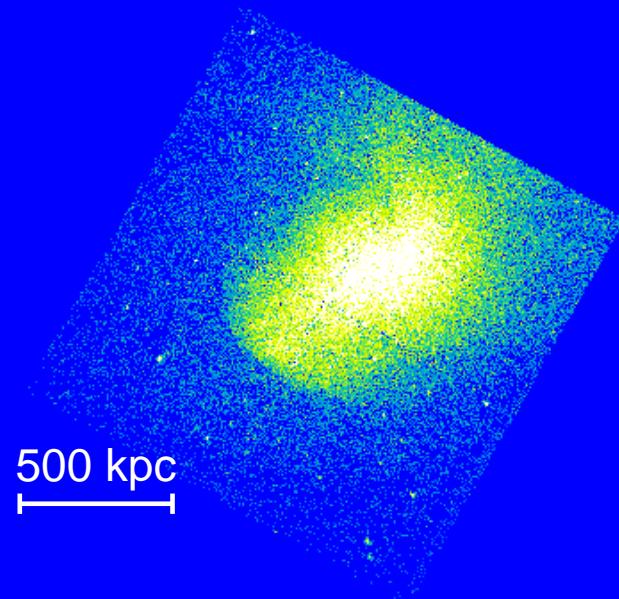
NGC 507 group



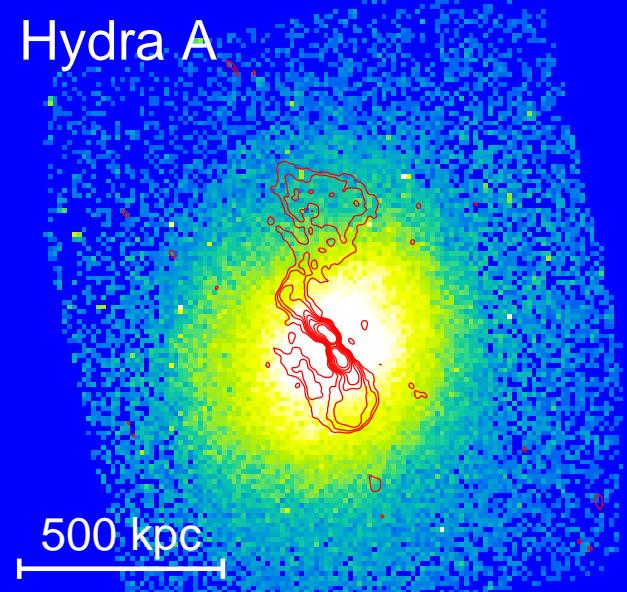
A2142



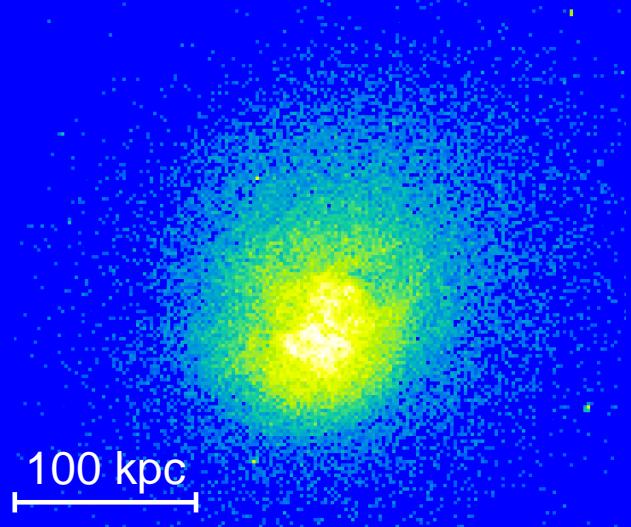
A3667



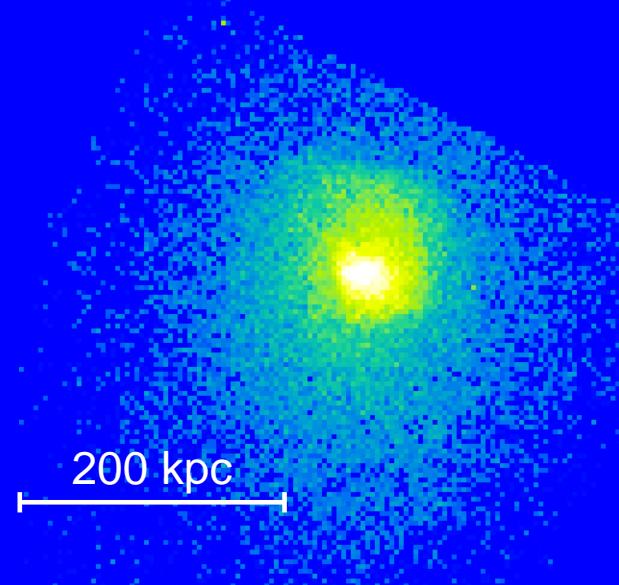
Hydra A



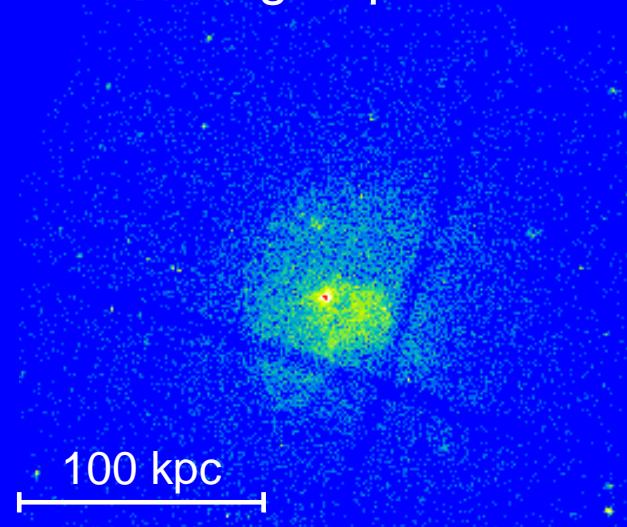
2A 0335+096



A496



NGC 507 group



CONCLUSIONS

- Shocks (1E 0657–56)
 - Merger dynamics
 - Plasma microphysics (electron-ion non-equilibrium etc.)
 - Constraints on the dark matter properties
- Heat conduction in the *bulk* of the cluster gas (A754): $\kappa < 0.1 \kappa_{\text{Sp}}$
- Cold fronts (A3667)
 - Hydrodynamics
 - Suppressed transport processes (diffusion, heat conduction)
 - Magnetic fields
 - Gas sloshing in the centers of relaxed clusters,
relation to radio bubbles (Hydra-A)
 - Limits on turbulence